Association between cardiometabolic health and objectively-measured, free-living sleep parameters in a rural African setting: a pilot study.

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Abstract

Objectives To investigate the relationship between objectively-measured, free-living sleep quantity and quality, and cardiometabolic health, in a rural African setting in 139 adults (≥40 years, female: n=99, male: n=40). Wrist-mounted, tri-axial accelerometry data was collected over nine days. Measures of sleep quantity and quality, and physical activity were extracted from valid minute-by-minute data. Self-reported data included behavioural, health and socio-demographic variables. Biological data included body composition, resting blood pressure and fasting blood glucose, insulin and lipids. Logistic regression models were constructed with insulin resistance (IR) and Cardiometabolic (CM) risk, as dependent variables, adjusting for socio-demographic, behavioural and biological factors. Results Nocturnal sleep time was longer in females (p=0.054) and sleep quality was better in males (p≤0.017). Few participants slept >9 hours/night (4-5%), and 46-50% slept <7 hours/night. IR and CM risk was higher in females (p≤0.006). In adjusted models, sleep variables were independently associated with IR (p<0.05). Sleep quantity was non-linearly associated with CM risk (p≤0.0398), and linearly associated with IR (p≤0.0444). Sleep quality was linearly related with CM risk and IR (p≤0.0201). In several models, sleep quantity and sleep quality measures were concurrently and significantly associated with IR (p≤0.044).

Introduction

Sleep health is closely linked to metabolic health [1], and while there is extensive literature from industrialised settings [2], there is a paucity of data from African settings, especially free-living, objective measures of sleep [3]. Within the South African context, self-reported long sleep duration is associated with poor cardiometabolic health in mainly urban settings [4, 5]. Given the lack of objectively-measured, free-living sleep parameters in any South African setting, the objective of this study was to use wrist-actigraphy to investigate the association between sleep parameters and cardiometabolic health in a rural African setting during a cross-sectional survey, and thus extend the findings of self-report sleep duration and cardiometabolic health [4-6]

Methods

Dikgale Health and Demographic Surveillance System site (DHDSS) sample

A convenience sample of 167 adults was recruited from the DHDSS site [7]. These participants formed part of a larger study cohort (≥40 years) [6, 8]. Trained field workers collected self-reported and measured data from participants by means of questionnaires, anthropometry, oscillometric blood pressure measurement, ultrasound scans, and venipuncture [6, 8]. We calculated body mass index (BMI, kg/m^2), and Conicity Index (CI) [9]. Questionnaire data included behavioural, health and socio-demographic variables [6, 8]. Nine day, free-living, wrist-mounted accelerometry data was collected [10]. The ultrasound scans were not considered for this analysis.

Blood sample collection and analysis

A registered nurse collected fasting blood samples. The samples were analysed centrally; procedures and calculations are described in detail elsewhere [8]. The Homeostasis Model Assessment of Insulin Resistance (HOMA-IR) was calculated from fasting blood glucose and insulin [11].

Criteria for Metabolic Syndrome

In accordance with the harmonized Joint Interim Statement (JIS) definition [12], the presence of the Metabolic Syndrome (MetS) required three of the following components, with waist circumference not a prerequisite: elevated waist circumference (WC): females ≥92 cm, males ≥86 cm; elevated triglycerides (TG): ≥1.7 mmol/l; reduced high-density lipoprotein cholesterol (HDL-C): men <1.0 mmol/l, women <1.3 mmol/l; elevated resting blood pressure ≥130/85mmHg or on hypertension treatment; and elevated fasting glucose (GC) ≥5.6 mmol/l or on diabetes treatment. For this study population-specific WC cut-points were chosen [13].

Using the five criteria from the JIS definition for MetS (JIS-MetS), we calculated sex-specific z-scores for HDL-C, TG, GC, WC and MAP (Mean Arterial Pressure), which were summed to create a MetS z-Score (MetSz) [14].

Accelerometer data collection and data reduction

Participants wore a small, light-weight, wrist-worn tri-axial accelerometer for 9 days (ActiGraph wGT3X-BT, Actigraph, LLC, Pensacola, FL, 2013) [15-18]. The preparation, initialization, mounting, data processing and extraction of physical activity (PA) and sleep parameters are described in detail elsewhere [10].

Vector Magnitude (VM)- and Ambulation-defined PA variables were defined as counts/day and steps/day, respectively [19]. Sleep indices included Total Sleep Time (TST), Nocturnal Sleep Time (NST), Sleep Efficiency (SE), Wake After Sleep Onset (WASO), Activity Counts during sleep (AC), and Sleep Fragmentation Index (SFI) [20-22]. Nocturnal periods were defined as 18h01-05h59. Sufficient sleep quantity and quality was defined as 7-9 hours [23] and ≥85% [24], respectively.

Statistical analysis

Descriptive statistics comprised means (one standard deviation), medians (inter-quartile range), variances (maximum, minimum) and frequencies. Relationships between categorical variables were examined through Fisher's Exact Test. For continuous data, independent *t* tests and Levene's test examined differences between sexes and risk groups. Where required a non-parametric test was employed. Bi-variate relationships were examined using linear regression.

Forced-entry binary logistic regression models were constructed to examine the relationship between MetS risk (low/high) according to the JIS definition [12], and tertiles (Q1=low/Q2/Q3=high) of sleep quantity and quality variables. Models were also constructed to examine the relationship between MetS risk and sleep quantity and quality categories [23-24]. Models were adjusted for socio-demographic (age, socio-economic status), behavioural (fruit and vegetable intake, sugar-sweetened beverages, tobacco and

alcohol usage, physical activity) and biological (sex, HIV status) variables. CI was not included as an independent variable because WC formed part of the JIS risk definition.

Forced-entry ordinal logistic regression models were constructed to examine the relationship between HOMA-IR levels (tertiles), and tertiles of sleep quantity and quality variables. Additional models were constructed to examine the relationship between HOMA-IR tertiles and sleep quantity and quality categories [23-24]. Models were adjusted for socio-demographic (age, socio-economic status), behavioural (fruit and vegetable intake, sugar-sweetened beverages, tobacco and alcohol usage, physical activity) and biological (sex, CI, HIV status) variables..

All covariates were entered as quantiles. Regression coefficients were expressed as odds ratios (OR±95% confidence intervals).

Goodness of fit criteria included Akaike's Information Criteria (AIC) (all models), pseudo R^2 (all models), Hosmer-Lemeshow test (Binary logistic) and Area Under the Curve (AUC) (Binary Logistic). Multicollinearity was assessed using Variance Inflation Factors (VIF) and Tolerance.

Post-hoc contrasts were run for binary and ordinal logistic regression models to test for linear and non-linear trends, and pairwise comparison of groups (Bonferroni correction).

Data were analysed using appropriate statistical software (Stata/SE for Windows: Release 15.1. College Station, TX: StataCorp LP, 2020). Significance for all inferential statistics was set at $p<0.05$.

Results

Of the 167 raw accelerometry data files, 157 had valid data for at least one weekday and one weekend day. Once combined with the questionnaire and biological data, 139 participants had complete data.

Females consumed more sugar-sweetened beverages (SSB), experienced poorer sleep quality, and were more physically active and insulin resistant (Table 1, $p≤0.07$). Males were leaner, used more alcohol and tobacco products and experienced lower people-to-bedroom density ($p≤0.040$). The JIS high risk group had a higher socio-economic status (SES), a lower HIV+ prevalence, were mostly obese, more insulin resistant, and likely to be in a partnered relationship (Table 1, $p≤0.040$).

[Insert Table 1 here]

In bi-variate analysis, sex, SES, CI, WC, BMI, SSB and WASO were significantly associated with HOMA-IR ($p≤0.05$). SES, BMI, CI, WC and HIV status were significantly related to MetSz ($p≤0.027$).

All models were significant (Figure 1A-F, Figure 2A-F. $p≤0.0095$) and there was no evidence of multicollinearity (VIF <1.5, Tolerance >0.75). The binary logistic regression models (Figure 1A-C, Figure 2A-C) showed good fit (Hosmer-Lemeshow: $p≥0.3744$; AUC: 0.808-0.877). The full models (OR±95% confidence intervals) for Figure 1A-F and Figure 2A-F are available in Additional File 1.

In binary logistic regression models (Figure 1A-C) males had significantly lower odds for JIS-MetS high risk (OR≈0.15, p≤ 0.006), and similarly for HIV+ status in the NST and SFI models (OR=0.25, p≤0.0035). Once adjusted for adiposity (CI), sex was no longer a significant factor (p≥0.097). However, HIV+ status remained a significant factor in most models (OR≈0.26, p≤0.048) (Figure 1A-C).

There was a significant non-linear trend (U-shaped) between JIS-MetS risk and NST (p=0.0196) (Figure 1A), such that for NST Q2, there was 80% less likelihood of being at high risk for JIS-MetS. There was also a significant difference in frequencies between NST Q1 and Q2 (p=0.021) (Figure 1A).

[Insert Figure 1 here]

There was a significant positive, linear trend between JIS-MetS risk and SFI (p=0.0001) (Figure 1C). The odds of high risk JIS-MetS for SFI Q3 was high (OR= 69.81, 8.44; 577.63), however the confidence intervals were wide. There were significant differences between the frequencies for Q3 versus Q1 and Q2 (p<0.001) (Figure 1C).

Being a current user of both alcohol and tobacco products carried a significant higher odds for JIS-MetS high risk in the NST (OR=4.51, p=0.034) and SFI (OR=6.55, p =0.023) models (Figure 1A-C).

In ordinal logistic regression models (Figure 1D-F), being in the VM Q2 level, significantly decreased the odds of being in HOMA-IR Q3 by a factor of ≈0.31 (p≤0.039). In contrast, for both CI Q2 and Q3 levels, the odds of being in HOMA-IR Q3 were significantly increased; Q2 OR≈2.9 and Q3 OR≈3.79, respectively (p≤0.045) (Figure 1D-F).

There was a significant linear trend between TST and HOMA-IR levels (p=0.0444) (Figure 1D). Compared to TST Q1 and Q2, being in TST Q3 (longest sleep time) increased the odds of being in the highest HOMA-IR level (Q3) by a factor of 2.84 (p=0.044) (Figure 1D).

There were significant linear relationships between SE and WASO, and HOMA-IR (p≤0.007) (Figure 1E). A high SE (Q3) was 85% less likely to result in HOMA-IR Q3 (p=0.001). Being in WASO Q2 and Q3 significantly increased the odds for HOMA-IR Q3; OR=3.17 and OR=6.75, respectively (p≤0.019).

SFI and AC were significantly associated with increasing HOMA-IR levels (p≤0.0201) (Figure 1F). Being in SFI Q2 and Q3 significantly increased the odds for HOMA-IR Q3, OR=4.67 (p=0.004) and OR=10.91 (p<0.001), respectively. For AC Q3 the odds of being in the HOMA-IR Q3 was 3.01 (p=0.020) (Figure 1F).

In the TST, NST, SE, WASO and AC models (Figure 1D-E), being in SSB Q2 and Q3, increased the likelihood for being in HOMA-IR Q3 by a factor of 3.51 to 4.77, but did not reach statistical significance (p=0.068 to p=0.098).

Sleep quantity and quality measures featured concurrently and significantly in the TST, SE and SFI models (Figure 1D-F) (p≤0.044).

Expressing sleep quantity and quality parameters in terms of sleep health guidelines, we found significant non-linear associations with JIS-MetS risk (p≤0.0308) (Figure 2A-F). The relationship between sleep categories for both TST and NST, and JIS-MetS risk were U-shaped, the nadir at 7-9 hours of sleep (Figure 2A-B).

[Insert Figure 2 here]

In binary logistic regression models (Figure 2A-C) males had significantly lower odds for JIS-MetS high risk (OR≈0.14, p= 0.004), and similarly for HIV+ (OR≈0.26, p≤0.0034). Once adjusted for adiposity (CI), sex was no longer a significant factor (p≥0.121). However, HIV+ status remained a significant factor in most models (OR≈0.23, p≤0.045) (Figure 2A-C).

In ordinal logistic regression models (Figure 2D-F) physical activity (VM Q2) significantly reduced the odds of being in HOMA-IR Q3 by a factor of ≈0.26 (p≤0.010). For both CI Q2 and Q3 levels, the odds of being in HOMA-IR Q3 were significantly increased (Q2 OR≈3.16, Q3 OR≈3.89, p≤0.022). For SE ≥85%, there was a 76% lower likelihood of being in HOMA-IR Q3 (p=0.010). Significantly more participants were classified as low HOMA-IR (Q1) in the SE ≥85% category (Figure 2D).

In the TST, NST and SE models (Figure 2D and 2F), being in SSB Q2, increased the odds for being in HOMA-IR Q3 by a factor of 3.24 to 3.65, but did not reach statistical significance (p=0.074).

Discussion

This analysis is novel in that, as far as the authors are aware, this is the first free-living, actigraphy-measured sleep and cardiometabolic health study from a South African setting.

The main findings of this analysis were first that sleep quality and quantity measures were independently associated with HOMA-IR, and to lesser extent JIS-MetS. Second, we found linear and non-linear (U-shaped) relationships between categories of sleep quantity and cardiometabolic risk.. Third, all sleep quality measures were consistently associated with HOMA-IR.

The level of JIS-defined MetS within rural sub-Sahara African settings [25] is 12.0% (95%CI: 4.0; 23.4) which is substantially lower than in our sample (35.3%). However, the mean prevalence reported in a rural South African setting for the ≥45 year age groups (males: 17.9%; females: 42.2%) [13] is similar to our results (males: 22.5%; females: 40.4%).

Our findings are in agreement with the linear relationship between sleep duration and HOMA-IR in black, urban women, although we found far more women had short sleep time compared with self-report measures [4]. A recent study from the METS group found long sleep duration in a black, urban South African sample [5].

Unadjusted sleep quantity did not differ significantly across the sexes, which is contrast to self-report measures [4]. Sleep quality was poorer in females, although sex did not reach significance in most

HOMA-IR models.

Some have speculated that poor sleep quality might be underpinning the long self-reported sleep durations in South African settings and hence the poorer cardiometabolic health associated with long sleep [4, 5]. Our results suggest that fragmented, poor sleep quality, independent of sleep duration might be more important than sleep duration. Future analyses need to explore the effect of the interaction between sleep quantity and quality, and cardiometabolic health [26].

In contrast with some self-reported PA studies [4], we found PA volume to be significantly and independently related to HOMA-IR, but not associated with JIS-MetS risk as in other self-report studies [5]. Interestingly, other lifestyle factors such as concurrent alcohol and tobacco use, and the consumption of SSB were independently associated with poor cardiometabolic health. The concurrent use of alcohol and tobacco is associated with poorer cardiometabolic health [27]. Although the association with SSB did not quite reach statistical significance, there is evidence that the consumption of SSB is linked with poor cardiometabolic health, even within rural environments [28].

In conclusion, we report the significant, independent importance of objectively-measured sleep quantity and quality in relation to cardiometabolic health in a rural South African setting.

Limitations

Due to the small sample size and cross-sectional, convenience sampling in this study, the results cannot be readily generalized, nor can causality be shown.

Abbreviations

BMI: body mass index

CI: Conicity Index

DHDSS: Dikgale Health and Demographic Surveillance System

GC: Glucose

HDL-C: High-density Lipoprotein Cholesterol

HIV: Human Immunodeficiency Virus

HOMA-IR: Homeostasis Model Assessment of Insulin Resistance

JIS: Joint Interim Statement

LDL-C: Low-density Lipoprotein Cholesterol

MAP: Mean Arterial Pressure

MetS: Metabolic Syndrome

MetSz: Metabolic Syndrome z-score

NST: Nocturnal Sleep Time

PA: Physical Activity

SE: Sleep Efficiency

SES: Socio-Economic Status

SFI: Sleep Fragmentation Index

SSB: Sugar sweetened beverages

TC: Total Cholesterol

TG: Triglyceride

TST: Total Sleep Time

VM: Vector Magnitude

WASO: Wake After Sleep Onset

WC: Waist circumference

Declarations

Ethics approval and consent to participate

Ethics approval for the AWI-Gen Phase 1 survey data and the accelerometer data collection was obtained from the Medunsa Research and Ethics Committee of the University of Limpopo (MREC/HS/195/2014:CR). The participants recruited into the original studies were informed about the study objectives, expected outcomes, benefits and the risks associated with it. Written informed consent was obtained from the participants prior to interviews and measurements.

Availability of data and material

The dataset analysed during the current study is available from the corresponding author on reasonable request.

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Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author's contributions

IC was the principal investigator of the accelerometer data on which this manuscript is based, who initiated the research and obtained funding, co-wrote and edited the research proposal, supervised the data entry, analyzed the data and wrote the first draft manuscript. MM co-wrote and edited the research proposal, collected field data, supervised the field work, performed the data entry, commented on the manuscript. HMM commented on- and contributed to the manuscript. All authors read and approved the final manuscript.

References

1. Smiley A, Wolter S, Nissan D. Mechanisms of Association of Sleep and Metabolic Syndrome. J Med Clin Res Rev. 2019;3:1-9.

2. Anothaisintawee T, Reutrakul S, Van Cauter E, Thakkinstian A. Sleep disturbances compared to traditional risk factors for diabetes development: systematic review and meta-analysis. Sleep Med Rev. 2016;30:11-24.

3. Cole HV, Owusu-Dabo E, Iwelunmor J, Newsome V, Meeks K, Agyemang C et al. Sleep duration is associated with increased risk for cardiovascular outcomes: a pilot study in a sample of community dwelling adults in Ghana. Sleep Med. 2017;34:118-25.

4. Rae DE, Pienaar PR, Henst RHP, Roden LC, Goedecke JH. Associations between long self-reported sleep, obesity and insulin resistance in a cohort of premenopausal black and white South African women. Sleep Health. 2018;4:558-64.

5. Rae DE, Dugas L, Roden L, Lambert EV, Bovet P, Plange-Rhule J et al. Associations between self-reported sleep duration and cardiometabolic risk factors in young African-origin adults from the five-country modeling the epidemiologic transition study (METS). Sleep Health. Forthcoming 2020.

6. Mashinya F, Alberts M, Cook I, Ntuli S. Determinants of body mass index by gender in the Dikgale Health and Demographic Surveillance System site, South Africa. Glob Health Action. 2018;11:1537613.

7. Alberts M, Dikotope SA, Choma SR, Masemola ML, Modjadji SE, Mashinya F et al. Health & Demographic Surveillance System Profile: The Dikgale Health and Demographic Surveillance System. Int J Epidemiol. 2015;44:1565-71.

8. Ali SA, Soo C, Agongo G, Alberts M, Amenga-Etego L, Boua RP et al. Genomic and environmental risk factors for cardiometabolic diseases in Africa: methods used for Phase 1 of the AWI-Gen population cross-sectional study. Glob Health Action. 2018;11:1507133.

9. Valdez R, Seidell JC, Ahn YI, Weiss KM. A new index of abdominal adiposity as an indicator of risk for cardiovascular disease. A cross-population study. Int J Obes Relat Metab Disord. 1993;17:77-82.

10. Cook I, Mohlabe M, Alberts M. Descriptive epidemiology of objectively-measured, free-living sleep parameters in a rural African setting. BMC Res Notes. 2020; 13:310.

11. Matthews DR, Hosker JP, Rudenski AS, Naylor BA, Treacher DF, Turner RC. Homeostasis model assessment: insulin resistance and beta-cell function from fasting plasma glucose and insulin concentrations in man. Diabetologia. 1985;28:412-9.

12. Alberti KG, Eckel RH, Grundy SM, Zimmet PZ, Cleeman JI, Donato KA et al. Harmonizing the metabolic syndrome: a joint interim statement of the International Diabetes Federation Task Force on Epidemiology and Prevention; National Heart, Lung, and Blood Institute; American Heart Association; World Heart Federation; International Atherosclerosis Society; and International Association for the Study of Obesity. Circulation. 2009;120:1640-5.

13. Motala AA, Esterhuizen T, Pirie FJ, Omar MA. The prevalence of metabolic syndrome and determination of the optimal waist circumference cutoff points in a rural South African community. Diabetes Care. 2011;34:1032-7.

14. Lee JC, Westgate K, Boit MK, Mwaniki DL, Kiplamai FK, Friis H et al. Physical activity energy expenditure and cardiometabolic health in three rural Kenyan populations. Am J Hum Biol.

2019;31:e23199-e.

15. Whitaker KM, Pettee Gabriel K, Jacobs DR, Jr., Sidney S, Sternfeld B. Comparison of Two Generations of ActiGraph Accelerometers: The CARDIA Study. Med Sci Sports Exerc. 2018;50:1333-40.

16. Migueles JH, Cadenas-Sanchez C, Ekelund U, Delisle Nyström C, Mora-Gonzalez J, Löf M et al. Accelerometer data collection and processing criteria to assess physical activity and other outcomes: a systematic review and practical considerations. Sports Med. 2017;47:1821-45.

17. Slater JA, Botsis T, Walsh J, King S, Straker LM, Eastwood PR. Assessing sleep using hip and wrist actigraphy. Sleep Biol Rhythms. 2015;13:172-80.

18. Full KM, Kerr J, Grandner MA, Malhotra A, Moran K, Godoble S et al. Validation of a physical activity accelerometer device worn on the hip and wrist against polysomnography. Sleep Health. 2018;4:209-16.

19. Wennman H, Pietilä A, Rissanen H, Valkeinen H, Partonen T, Mäki-Opas T et al. Gender, age and socioeconomic variation in 24-hour physical activity by wrist-worn accelerometers: the FinHealth 2017 Survey. Sci Rep. 2019;9:6534.

20. Ancoli-Israel S, Martin JL, Blackwell T, Buenaver L, Liu L, Meltzer LJ et al. The SBSM guide to actigraphy monitoring: clinical and research applications. Behav Sleep Med. 2015;13:S4-S38.

21. Chung S, Youn S, Lee C, Jo M-W, Park J, Jo SW et al. Environmental noise and sleep disturbance: night-to-night variability of sleep/wake pattern. Sleep Med Res. 2016;7:78-81.

22. Ko Y, Lee J-Y. Effects of feet warming using bed socks on sleep quality and thermoregulatory responses in a cool environment. J Physiol Anthropol. 2018;37:13.

23. Hirshkowitz M, Whiton K, Albert SM, Alessi C, Bruni O, DonCarlos L et al. National Sleep Foundation's sleep time duration recommendations: methodology and results summary. Sleep Health. 2015;1:40-3.

24. Fung MM, Peters K, Ancoli-Israel S, Redline S, Stone KL, Barrett-Connor E. Total sleep time and other sleep characteristics measured by actigraphy do not predict incident hypertension in a cohort of community-dwelling older men. J Clin Sleep Med. 2013;9:585-91.

25. Jaspers Faijer-Westerink H, Kengne AP, Meeks KAC, Agyemang C. Prevalence of metabolic syndrome in sub-Saharan Africa: A systematic review and meta-analysis. Nutr Metab Cardiovasc Dis. 2020;30:547-65.

26. Lu K, Zhao Y, Chen J, Hu D, Xiao H. Interactive association of sleep duration and sleep quality with the prevalence of metabolic syndrome in adult Chinese males. Exp Ther Med. 2020;19:841-8.

27. Slagter SN, van Vliet-Ostaptchouk JV, Vonk JM, Boezen HM, Dullaart RPF, Kobold ACM et al. Combined effects of smoking and alcohol on Metabolic Syndrome: The LifeLines Cohort Study. PLoS One. 2014;9:e96406.

28. Vorster HH, Kruger A, Wentzel-Viljoen E, Kruger HS, Margetts BM. Added sugar intake in South Africa: findings from the Adult Prospective Urban and Rural Epidemiology cohort study. Am J Clin Nutr. 2014;99:1479-86.

Tables

Table 1 Descriptive statistics of demographic, behavioural and biological characteristics by sex and cardio-metabolic risk

	Sex			Cardio-metabolic Risk (JIS Harmonized definition)		
	Females (n=99)	Males (n=40)	p-values	Low Risk (<3 factors) (n=90)	High Risk (≥3 factors) (n=49)	p-values
Socio-demographic						
Age (years)	52.0 (6.9)	53.9 (7.5)	0.165	51.9 (7.4)	53.9 (6.3)	0.112
Marital status (Married/Co-habiting) †	54.5 (54)	55.0 (22)	0.648	46.7 (42)	69.4 (34)	**0.040**
Level of education (formal education) †	94.9 (94)	97.5 (39)	0.978	95.6 (96)	95.9 (47)	0.766
Employed (Yes) †	27.3 (27)	27.5 (11)	0.567	73.3 (66)	71.4 (35)	0.844
SES Quintile	3.6 (1.3)	3.5 (1.3)	0.652	3.4 (1.3)	4.0 (1.3)	**0.008**
Housing density *						
People/room	0.86 (0.75)	0.69 (0.78)	0.065	0.79 (0.75)	0.83 (0.88)	0.220
People/bedroom	1.67 (1.25)	1.37 (1.00)	**0.040**	1.50 (1.25)	1.67 (1.0)	0.330
Behavioural						
Diet *						
Fruit and vegetable intake (servings/day)	1.29 (1.00)	1.14 (0.00)	0.070	1.14 (1.00)	1.29 (2)	0.194
Sugar sweetened	0.29	0.29	**0.010**	0.29	0.29	0.131

beverages (servings/day)	(0.10)	(0.00)		(0.00)	(1.00)	
Health-compromising						
Alcohol & Tobacco use (both current; Yes)	8.1 (8)	45.0 (18)	**<0.001**	18.9 (17)	18.4 (9)	0.972
Objectively-measured Sleep						
Quantity						
Sleep Time (minutes/day)						
Total	458 (67)	456 (106)	0.901	456 (73)	460 (92)	0.818
Nocturnal *	434 (61)	411 (72)	0.054	425 (60)	431 (73)	0.639
Sufficient sleep categories †						
Total sleep time						
<7 hours/day	32.3 (32)	40.0 (16)	0.666	31.1 (28)	40.8 (20)	0.115
7-9 hours/day	52.5 (52)	45.0 (18)		56.7 (51)	38.8 (19)	
>9 hours/day	15.2 (15)	15.0 (6)		12.2 (11)	20.4 (10)	
Nocturnal sleep time						
<7 hours/night	45.5 (45)	50.0 (22)	0.546	45.6 (41)	53.1 (26)	0.122
7-9 hours/night	50.5 (50)	40.0 (16)		52.2 (47)	38.8 (19)	
>9 hours/night	4.0 (4)	5.0 (2)		2.2 (2)	8.2 (4)	
Quality						
Wake after sleep onset (minutes)	54 (16)	44 (17)	**0.001**	51 (18)	51 (15)	0.839
Sleep efficiency (%)	87.6 (4.2)	89.5 (4.6)	**0.017**	88.2 (4.6)	88.0 (3.9)	0.789

Achieved ≥85% †	79.8 (79)	82.5 (33)	0.816	80.0 (72)	81.6 (40)	1.000
Activity counts during sleep (counts)	35 057 (9223)	27 448 (9223)	**0.001**	32 633 (9223)	33 298 (9223)	0.761
Sleep fragmentation index (%)	26.7 (7.0)	28.2 (6.6)	0.243	26.5 (6.9)	28.3 (6.8)	0.151
Objectively-measured Physical Activity						
VM counts/day (x 10^6)	2.49 (0.63)	2.00 (0.77)	**<0.001**	2.33 (0.75)	2.38 (0.60)	0.669
Ambulation (steps/day)	14 288 (3691)	15 132 (6492)	0.443	14 470 (432)	14 681 (4378)	0.838
<u>Biological</u>						
Females (Yes)	-	-	-	65.6 (59)	81.6 (40)	0.052
Waist circumference (cm)	93.0 (16.3)	80.8 (9.7)	**<0.001**	83.5 (14.0)	100.7 (12.4)	**<0.001**
Body mass index (kg/m^2)	30.4 (7.6)	21.7 (3.8)	**<0.001**	25.3 (6.9)	32.6 (7.2)	**<0.001**
Body mass index categories †						
Under- weight (<18.5 kg/m^2)	3.0 (3)	17.5 (7)	**<0.001**	10.0 (9)	2.0 (1)	**<0.001**
Normal weight (18.5-24.9 kg/m^2)	21.2 (21)	55.0 (22)		43.3 (39)	8.2 (4)	
Overweight (25 – 29.99 kg/m^2)	23.2 (23)	27.5 (11)		24.4 (22)	24.5 (12)	
Obese (≥30 kg/m^2)	52.5 (52)	0.0 (0.0)		22.2 (20)	65.3 (32)	
Conicity Index	1.23 (0.10)	1.23 (0.08)	0.940	1.20 (0.09)	1.29 (0.08)	**<0.001**

HIV status (Yes) †	22.2 (22)	25.0 (10)	0.824	28.9 (26)	12.2 (6)	**0.034**
Resting SBP (mmHg)	126 (20)	126 (24)	0.870	120 (17)	138 (22)	**<0.001**
Resting DBP (mmHg)	81 (11)	78 (13)	0.157	77 (11)	86 (12)	**<0.001**
MAP (mmHg)	96 (13)	94 (16)	0.384	91 (12)	104 (14)	**<0.001**
Parity * §	4 (2)	-	-	4 (2)	4 (3)	0.775

Cardio-metabolic

Total Cholesterol (mmol/l)	4.10 (1.36)	3.72 (1.30)	0.139	4.00 (1.44)	3.98 (1.15)	0.972
HDL-Cholesterol (mmol/l)	1.10 (0.47)	1.07 (0.52)	0.865	1.16 (0.53)	0.95 (0.34)	**0.007**
LDL-Cholesterol (mmol/l)	2.51 (1.10)	2.15 (0.96)	0.072	2.40 (1.14)	2.40 (0.95)	0.997
Triglyceride (mmol/l)	1.10 (0.58)	1.10 (0.61)	0.959	0.95 (0.47)	1.38 (0.68)	**<0.001**
Glucose (mmol/l)	5.32 (1.89)	5.41 (1.86)	0.811	4.85 (1.26)	6.26 (2.42)	**<0.001**
Insulin (µIU/ml) *	6.91 (7.75)	3.14 (5.61)	**0.001**	4.12 (6.27)	7.60 (7.05)	**0.001**
HOMA-IR *	1.51 (1.91)	0.71 (1.72)	**0.003**	0.90 (1.53)	2.09 (1.96)	**0.003**
HOMA-IR categories †						
Q1 (≤0.82)	-	-	-	42.2 (38)	16.3 (8)	**0.002**
Q2 (0.83 - 2.09)	-	-		33.3 (30)	34.7 (17)	
Q3 (2.10)	-	-		24.4 (22)	49.0 (24)	
Metabolic Syndrome (JIS Harmonised definition) †						
No risk factor	11.1	12.5	**0.006**	-	-	-

	(11)	(5)				
1 risk factor	15.2 (15)	42.5 (17)	-		-	
2 risk factors	33.3 (33)	22.5 (9)	-		-	
≥3 risk factors	40.4 (40)	22.5 (9)	-		-	
Waist circumference (male: ≥86cm, females: ≥92cm)	58.6 (58)	35.0 (14)	**0.015**	31.1 (28)	89.8 (44)	**<0.001**
Blood pressure (SBP: ≥135 mmHg, DBP: ≥85 mmHg)	42.4 (42)	50.0 (20)	0.266	27.8 (25)	75.5 (37)	**<0.001**
HDL-Cholesterol (male:<1 mmol/, female<1.3 mmol/l)	72.7 (72)	45.0 (18)	**0.003**	53.3 (48)	85.7 (42)	**<0.001**
Triglyceride ≥1.7 mmol/l))	15.2 (15)	7.5 (3)	0.276	5.6 (5)	26.5 (13)	**0.001**
Glucose (≥5.6 mmol/l)	19.2 (19)	27.5 (11)	0.362	11.1 (10)	40.8 (20)	**<0.001**
Metabolic Syndrome z-score	7.7 (-7.3; 9.4)‡	6.1 (-4.5; 6.6)	**<0.001**	-1.17 (2.50) *	2.21 (1.97)	0.599

Data reported as mean (SD), * median (IQR), † % (n) or ‡ variance (minimum; maximum); § low risk: n=59 , high risk: n=40; DBP: Diastolic Blood Pressure; HOMA-IR: Homeostasis Model Assessment of Insulin Resistance; HIV: Human Immunodeficiency Virus; JIS: Joint Interim Statement; MAP: Mean Arterial Pressure = ⅓DBP + ⅔SBP; Nocturnal: 18h01 - 05h59; SES: Socio-Economic Status; SBP: Systolic Blood Pressure; VM: Vector Magnitude
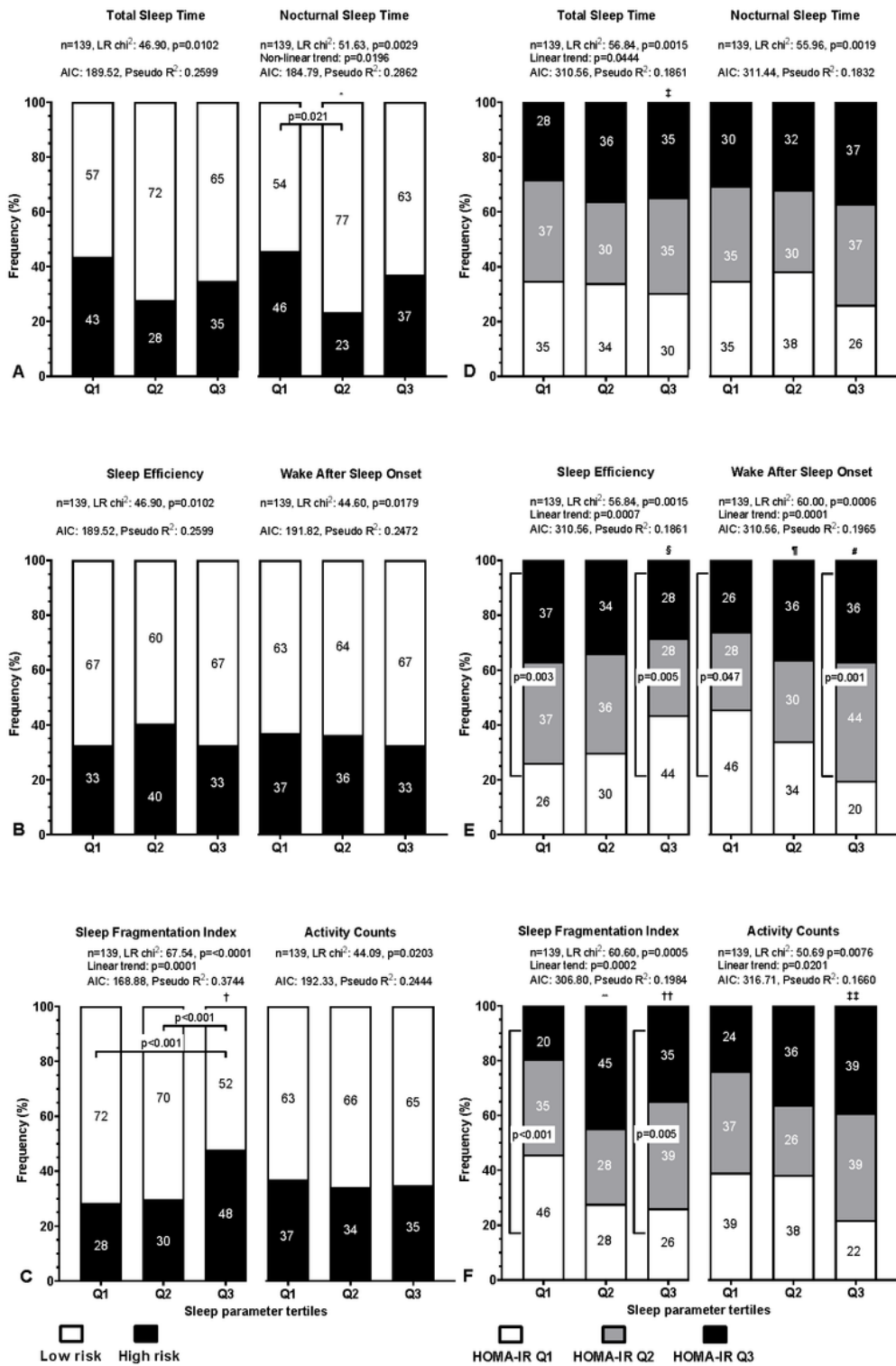
Figures

Figure 1

Cardiometabolic risk categories across quantiles of accelerometry-derived sleep-quantity and -quality measures. A-C: Binary risk categories for the JIS Harmonised Definition A. Nocturnal sleep time (minutes) and Total sleep time (minutes), * OR 0.20 (0.05, 0.71); B. Sleep efficiency (percentage) and Wake after sleep onset (minutes); C. Sleep fragmentation index (%) and Activity counts during sleep (counts), †OR 69.80 (8.44, 577.63) Fully-adjusted binary logistic regression models (socio-demographic, behavioural,

biological), excluding body composition measures (see Additional File 1). D-F: Tertiles of HOMA-IR D. Nocturnal sleep time (minutes) and Total sleep time (minutes), ‡ OR 2.84 (1.03, 7.83); E. Sleep efficiency (percentage) and Wake after sleep onset (minutes), § OR 0.15 (0.05, 0.45), ¶ OR 3.17 (1.21, 8.32), # OR 6.75 (2.54, 17.91); F. Sleep fragmentation index (%) and Activity counts during sleep (counts), ** OR 4.67 (1.64, 13.30), †† OR 10.91 (3.11, 38.33), ‡‡ OR 3.01 (1.19, 7.64) Fully-adjusted ordinal logistic regression models (socio-demographic, behavioural, biological), including body composition measures (Conicity Index) (see Additional File 1). The horizontal lines between the sleep parameter tertiles (Q1-Q3) and vertical lines between the HOMA-IR tertiles (HOMA-IR Q1/Q2/Q3) indicate significant post hoc differences between tertiles at either end of the line. Cut-points for sleep parameter quantiles (Q1/Q2/Q3) are presented in Table S1 (see Additional File 2).
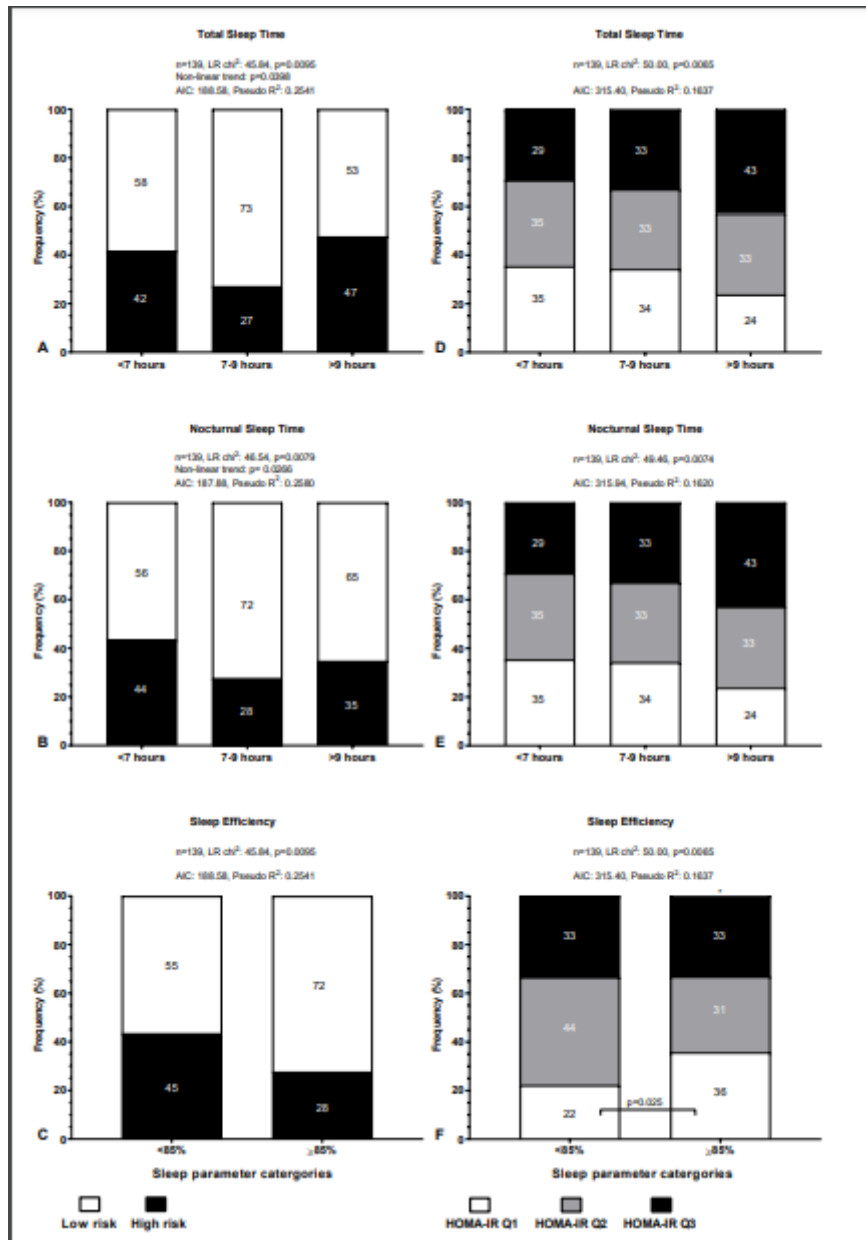

Figure 2

Cardiometabolic risk categories across categories of accelerometry-derived sleep-quantity and -quality measures. A-C: Binary risk categories for the JIS Harmonised Definition A. Total sleep time (minutes); B. Nocturnal sleep time (minutes); C. Sleep efficiency (percentage) Fully-adjusted binary logistic regression models (socio-demographic, behavioural, biological), excluding body composition measures (see Additional File 1). D-F: Tertiles of HOMA-IR D. Total sleep time (minutes); E. Nocturnal sleep time (minutes); F. Sleep efficiency (percentage), * OR 0.24 (0.08, 0.71) Fully-adjusted ordinal logistic regression models (socio-demographic, behavioural, biological), including body composition measures (Conicity Index) (see Additional File 1). The horizontal lines between the sleep parameter tertiles (Q1-Q3) indicate significant post hoc differences between tertiles at either end of the line.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- FigureS1.pdf
- ModelsFigures12.xlsx
- TableS1.docx