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The diabetes mellitus comorbidity index in European Union member states based on the 2019 European Health Interview Survey

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Multiple chronic conditions reduce the quality of life and increase healthcare needs for people with diabetes mellitus (DM). This study aims to describe the prevalence of comorbidities associated with DM in the European Union (EU) at national and sub-national levels and to assess the utility of a comorbidity burden index. The study was carried out using microdata from European Health Interview Survey 2019 including adults aged 25 and older with DM from 26 EU member states ($n = 20,042$). The comorbidity index was calculated for 9 chronic conditions using the self-rated general health of individuals and disability weights obtained from the Global Burden of Disease 2019. Beta regression analysis was performed to evaluate the association between the comorbidity index and several determinants. A higher comorbidity index was found in sub-populations exhibiting lower education, unemployment or other labour status, lower income, rural residence, and poor health behaviours including obesity, physical inactivity, and poor diet. A higher comorbidity burden was observed in Eastern and Southern European countries and specific subregions within each country. The comorbidity index has the potential to identify regions and subpopulations with the highest disability burden and to help develop interventions to improve the quality of life of people with DM.

The concept of comorbidity refers to the presence of one or more additional conditions that co-occur with a primary condition, either physiological or psychological. Comorbidity may describe conditions that occur simultaneously but independently or interrelated conditions[1]. Comorbidity can lead to poorer health outcomes, increased complexity of clinical management, and higher healthcare expenditures.

The terms comorbidity and multimorbidity are used interchangeably in the literature, but their difference should be underlined[2]. Comorbidity refers to the presence of one or more illnesses in addition to a primary illness, with one illness taking priority over the others, while multimorbidity refers to the presence of two or more long-term illnesses without an illness taking priority over the others. Such distinction is crucial as it can significantly impact the treatment and care provided to patients.

This article focuses on the comorbidities of diabetes mellitus (DM). In the European Union (EU), the comorbidity of DM is a significant problem, with over 33 million people living with DM in the EU[3]. Individuals with DM often face challenges in self-managing their condition with limited support from healthcare professionals, leading to financial burden, psychosocial issues, and reduced quality of life[3]. The development of certain comorbid conditions can dramatically increase the probability of developing other diseases[4], leading to a significant reduction in the quality of life in individuals living with DM over time. Furthermore, type 2 diabetes mellitus (T2DM) patients with multiple comorbidities are likely to experience high levels of polypharmacy[5], and comorbidity increases the demand for health care substantially in patients with DM[6]. Consequently, the increasing longevity and DM prevalence require an understanding of the complexity of comorbidity patterns and capturing the relationship with common risk factors to develop strategies to reduce the disability burden associated with DM.

The comorbidities associated with DM include several conditions involving cardiovascular diseases such as hypertension and ischaemic heart disease, obesity, dyslipidaemia, and microvascular complications such as

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retinopathy, nephropathy and neuropathy[7,8]. These comorbidities frequently overlap with DM due to common underlying risk factors and contribute to the complex challenge of effectively controlling the disease[8,9]. Among the risk factors, the analysis of the relationship between socioeconomic status (SES) and DM is vital, given the significant influence of SES on the prevalence, management, and outcomes of DM. Even though the relationship between SES and DM is a topic of considerable research interest, there remain significant gaps in our understanding of how SES affects DM comorbidities, particularly with regard to the geographical variability of these relationships[10].

Another important aspect is the identification of appropriate tools to evaluate DM comorbidities. Comorbidity measures can be classified according to discrete conditions, simple counts, organ system dysfunction/function, conditions weighted and combined into indices, or other approaches[11]. Commonly used measures to assess comorbidity include the Charlson Comorbidity Index, Elixhauser Comorbidity Index, Chronic Disease Score, Adjusted Clinical Group (ACG) Indices, and the Number of Diagnoses comorbidity measure[12].

Andreella and coauthors recommended a new comorbidity burden index for the Italian framework[13]. The index was developed by analyzing data from a surveillance system and using disability weights from the Global Burden of Diseases (GBD) project[14]. Disability weights are used to measure the health loss associated with specific health conditions[15] and are an essential factor in estimating the amount of lifetime lost due to living with a particular disease. In 1996, the GBD established the initial disability weights, and since then, various alternatives with different design choices have been proposed[16].

This analysis aimed to comprehensively describe the prevalence of comorbidities associated with DM in the EU population at the national and sub-national levels. In addition, we aimed to evaluate the utility of a comorbidity burden index incorporating disability weights from the Global Burden of Disease (GBD) project to characterise populations of varying socioeconomic status and to assess the burden of DM-related comorbidities.

Methods

Study design and study population

This study analysed secondary data from the European Health Interview Survey (EHIS) 2019, which is a cross-sectional population-based survey collecting data in EU members states. Microdata were obtained from the Statistical Office of the European Union (Eurostat)[17].

The study population included adults aged 25 years or older from 26 EU Member States: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherland, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden. The dataset comprised 20,042 observations of individuals who reported having diabetes mellitus (DM). DM was assessed by the self-reported question "Have you had diabetes in the last 12 months?", those who answered yes, were considered as having DM and were included in the study sample.

Study variables

Demographic variables included in the study covered sex and age groups (25–34, 35–44, 45–54, 55–64, 65–74, 75 and above). Socioeconomic variables included educational attainment level (less than primary/primary education, secondary education, and tertiary education), labor status (employed, unemployed, and other category including student, retired, fulfilling domestic tasks, permanently disabled, compulsory military or civilian service, and other), place of residence (rural and urban), net monthly equalized income of the household the respondent belongs to in quintiles (1st income quintile, 2nd income quintile, 3rd income quintile, 4th income quintile, and 5th income quintile), where the first quintile group represents 20% of the population with the lowest income, and the fifth quintile group represents the 20% of the population with the highest income. Lifestyle-related variables included BMI (underweight/normal weight, overweight and obese), smoking (non-smoker and smoker), frequency of eating fruits and vegetables (once or more a day, 1–6 times a week, and less than once a week or never) and physical activity. Physical activity was measured as the frequency of walking at least 10 min per day and was categorized as none or one day per week and two days or more per week.

Comorbidity index calculation

The comorbidity index was calculated using individual-level data, following the approach by Andreella and coauthors[13], for specific comorbid conditions among individuals who reported having DM in the EHIS 2019 dataset. Individuals were considered to have the selected diseases if they responded positively to the question: "Have you had the following diseases in the last 12 months?". The selected comorbidities included asthma, chronic bronchitis, chronic obstructive pulmonary disease, emphysema, myocardial infarction or chronic consequences of myocardial infarction, coronary heart disease or angina pectoris, stroke or chronic consequences of stroke, kidney problems, and depression. The disability weights obtained from the Global Burden of Disease 2019 study[18] and data from the self-perceived general health question in the EHIS 2019 were used to calculate the comorbidity index for these conditions in the DM population. First, to select the disability weights which refer to these conditions in GBD 2019, text mining was applied using the names of diseases in the "Health state name" category of the disability weights. Two investigators (NK and NM) independently selected the disability weights, and disagreements were resolved through discussion (see Supplementary Table S1). The GBD disability weights are measured on a scale ranging from 0 to 1, where 0 represents full health and 1 equals death[18,19].

Second, since GBD provides different disability weights based disease severity, we determined the disability weights using data from the self-perceived health variable in EHIS 2019. We focused on the following question: "How is your health in general?". Depending on the responses, if the value was 1 (very good), 2 (good) or 3 (fair), we applied the minimum disability weight for each disease. The mean value of the weights was used if the value of self-perceived health was 4 (bad), and the maximum value of the weights was employed if the self-perceived health was 5 (very bad), representing the highest severity. For individuals reporting only DM

and very good/good/fair health status, the minimum disability weight used was 0.049 (as specified in GBD 2019). For individuals with multiple conditions, the disability weights were combined using the multiplicative approach to account for multimorbidity. This approach was chosen because it produces more accurate results when constructing a comorbidity index compared to other methods[13]. Furthermore, the multiplicative approach is also a method used by GBD for combining disability weights[20,21]. The comorbidity index was calculated at the individual level and then aggregated to compute mean values for each country, and where applicable, for each Nomenclature of Territorial Units for Statistics (NUTS 2).

Statistical analysis

The distribution of the variables was described and compared for female and male respondents. Percentages were used as descriptive statistics. To perform bivariate comparisons, the Pearson chi-square test was used to assess the independence of study variables across sex, and Bonferroni correction for multiple comparisons was applied to assess the significant differences between groups. The effect size was estimated using Cramer's V. Mixed-effects beta regression model was used to evaluate the association between the comorbidity index and several demographic, socioeconomic, and lifestyle variables using pooled data with the country as the random effect. Mixed-effects beta regression was chosen as the outcome variable ranged from 0.049 to 0.993. This method is flexible enough to account for different distribution shapes without transformation of the outcome variable. Additionally, it allows for the modeling of data with clustering by country[22]. The estimated regression coefficient ($\widehat{\beta}$) and 95% confidence intervals (CI) were reported. Estimated values of the comorbidity index across different variables and age groups were also presented. Marginal effects were also calculated for variables across each country. p-values smaller than 0.05 were considered statistically significant. All analyses and graphs were performed and produced using R software, and the map was created using STATA IC version 13.0 software (StataCorp LP, College Station, Texas, USA). The *glmmTMB* package[23] in R was used for the mixed beta regression analyses, and the *marginaleffects* package[24] was used to obtain marginal effects.

Ethics statements

This study is based on a secondary analysis of a public and anonymized dataset, which had obtained ethics approval on a national level from the institutions responsible for the survey implementation and, therefore, required no additional ethics approval. EHIS 2019 was conducted according to Commission Regulation (EU) No. 2018/255. Participants gave informed consent to participate in the study before taking part. Our study is based on the approved Eurostat research proposal project RPP 266/2020-LFS-EHIS.

Results

Table 1 shows the sociodemographic and lifestyle characteristics of the study population by sex. The study sample consisted of 20,042 participants with DM aged 25 years and older. The majority of respondents belonged to the 65–74 years (33.9%) and 75 years or older (32.5%) age groups, and 51.4% ($n = 10{,}301$) of the study sample was women. Overall, 47.3% of participants had a primary level of education, two-thirds (67.8%) of them were living in urban areas, and the majority (78.0%) belonged to the "other" category in terms of their labor status, including retired, disabled, etc. A high proportion of participants with DM were overweight (41.8%) or obese (36.2%), 15.6% of them were smokers, and 67.8% of participants were engaged in two or more days per week of walking at least 10 min a day. Almost half of the individuals (49.1%) reported eating vegetables once or more a day, and 62.8% of them reported daily fruit consumption. (Table 1)

Figure 1 shows the number of individuals and means of the comorbidity index in the presence of certain chronic diseases among individuals with DM. The values in the diagonal cells refer to the presence of specific chronic conditions and DM (e.g., the prevalence of asthma was 8.02% in people with DM with a mean comorbidity index of 0.308). The remaining cells show the prevalence (in blue) and the comorbidity index (in red) in cases where two chronic conditions co-exist in individuals with DM. The most prevalent comorbid conditions among patients with diabetes were coronary heart disease (12.85%) and depression (12.57%). The highest comorbidity burden was observed in the case of the coexistence of depression and cardiovascular conditions, including myocardial infarction (0.661) and stroke (0.660).

The results of the regression analysis are shown in Table 2. Those aged 45–54 had a higher comorbidity index ($\widehat{\beta} = 0.167$, p-value=0.015) than the reference age group (25–34). In addition, having secondary ($\widehat{\beta} = -0.072$, p-value < 0.001) or higher education ($\widehat{\beta} = -0.085$, p-value < 0.001) are both negatively associated with the comorbidity index. Moreover, being unemployed ($\widehat{\beta} = 0.227$, p-value < 0.001) or in another labor status ($\widehat{\beta} = 0.331$, p-value < 0.001) compared to being employed were significantly associated with a higher comorbidity index. The comorbidity index significantly decreased for higher levels of income among participants with DM (2nd quintile: $\widehat{\beta} = -0.082$, p-value < 0.001; 3rd quintile: $\widehat{\beta} = -0.107$, p-value < 0.001; 4th quintile: $\widehat{\beta} = -0.121$, p-value < 0.001; 5th quintile: $\widehat{\beta} = -0.154$, p-value < 0.001) compared to the lowest income quintile. Regarding lifestyle factors, participants being obese ($\widehat{\beta} = 0.081$, p-value<0.001) had a significantly higher comorbidity index than the reference group of normal weight. Less frequent (less than once a week or never) consumption of fruits ($\widehat{\beta} = 0.102$, p-value<0.001) or vegetables ($\widehat{\beta} = 0.251$, p-value<0.001) was associated with a significantly higher comorbidity index compared to daily frequency. Engaging in PA (walking) two or more days per week was significantly associated with a lower comorbidity index ($\beta = -0.354$, p-value<0.001) compared to those doing physical activity one day per week or none. These comments are valid under the usual conditional assumption, i.e., keeping the other covariates fixed and considering the same country. Country specific results are available in the Supplementary file (see Supplementary Table S2).

Figure 2 shows the estimated values of the comorbidity index across age groups and by sex for socioeconomic and lifestyle factors. Overall, the comorbidity index increases with age, with a sharp increase after age 65 for all risk factor categories. A higher comorbidity index was found in sub-populations characterized by a lower level of

		Total		Men		Women				
		n	%	n	%	n	%	χ^2	*p* -value	Cramér's V
Total		20,042		9,741	48.6%	10,301	51.4%			
Age group	25–34	233	1.2%	92	0.9%	141	1.4%	249.6	< **0.001**	0.11
	35–44	545	2.7%	265	2.7%	280	2.7%			
	45–54	1,596	8.0%	907	9.3%	689	6.7%			
	55–64	4,353	21.7%	2,374	24.4%	1,979	19.2%			
	65–74	6,798	33.9%	3,399	34.9%	3,399	33.0%			
	75+	6,517	32.5%	2,704	27.8%	3,813	37.0%			
Education	Primary	9,475	47.3%	3,966	40.7%	5,509	53.5%	381.4	< **0.001**	0.14
	Secondary	7,136	35.6%	3,723	38.2%	3,413	33.1%			
	Higher	3,431	17.1%	2,052	21.1%	1,379	13.4%			
Employment status	Employed	3,829	19.1%	2,407	24.7%	1,422	13.8%	416.1	< **0.001**	0.14
	Unemployed	582	2.9%	329	3.4%	253	2.5%			
	Other	15,631	78.0%	7,005	71.9%	8,626	83.7%			
Income quintiles	1st quintile	4,453	22.2%	1,639	16.8%	2,814	27.3%	595.3	< **0.001**	0.17
	2nd quintile	5,146	25.7%	2,213	22.7%	2,933	28.5%			
	3rd quintile	4,264	21.3%	2,289	23.5%	1,975	19.2%			
	4th quintile	3,494	17.4%	1,981	20.3%	1,513	14.7%			
	5th quintile	2,685	13.4%	1,619	16.6%	1,066	10.3%			
Residence	Urban	13,598	67.8%	6,739	69.2%	6,859	66.6%	15.5	< **0.001**	0.03
	Rural	6,444	32.2%	3,002	30.8%	3,442	33.4%			
Smoking	Smoker	3,124	15.6%	1,964	20.2%	1,160	11.3%	301.5	< **0.001**	0.12
	non-smoker	16,918	84.4%	7,777	79.8%	9,141	88.7%			
Fruit consumption	Daily	12,583	62.8%	5,948	61.1%	6,635	64.4%	24.1	< **0.001**	0.03
	1–6 times a week	6,151	30.7%	3,124	32.1%	3,027	29.4%			
	Less than once a week or never	1,308	6.5%	669	6.9%	639	6.2%			
Vegetable consumption	Daily	9,833	49.1%	4,589	47.1%	5,244	50.9%	29.5	< **0.001**	0.04
	1–6 times a week	9,256	46.2%	4,660	47.8%	4,596	44.6%			
	Less than once a week or never	953	4.8%	492	5.1%	461	4.5%			
BMI	Normal/underweight	4,405	22.0%	1,877	19.3%	2,528	24.5%	152.4	< **0.001**	0.09
	Overweight	8,373	41.8%	4,474	45.9%	3,899	37.9%			
	Obese	7,264	36.2%	3,390	34.8%	3,874	37.6%			
Physical activity (walking)	None or one day	6,444	32.2%	2,901	29.8%	3,543	34.4%	48.8	< **0.001**	-0.05
	Two days or more	13,598	67.8%	6,840	70.2%	6,758	65.6%			

Continued

		Total		Men		Women				
		n	%	n	%	n	%	χ^2	*p* -value	Cramér's V
Country	Austria	954	4.8%	500	5.1%	454	4.4%	361.2	**< 0.001**	0.13
	Belgium	397	2.0%	212	2.2%	185	1.8%			
	Bulgaria	560	2.8%	243	2.5%	317	3.1%			
	Cyprus	533	2.7%	280	2.9%	253	2.5%			
	Czechia	922	4.6%	417	4.3%	505	4.9%			
	Germany	1,907	9.5%	1,053	10.8%	854	8.3%			
	Denmark	269	1.3%	151	1.6%	118	1.1%			
	Estonia	318	1.6%	106	1.1%	212	2.1%			
	Greece	769	3.8%	365	3.7%	404	3.9%			
	Spain	1,751	8.7%	929	9.5%	822	8.0%			
	Croatia	302	1.5%	167	1.7%	135	1.3%			
	Hungary	421	2.1%	201	2.1%	220	2.1%			
	Ireland	509	2.5%	241	2.5%	268	2.6%			
	Italy	95	0.5%	55	0.6%	40	0.4%			
	Lithuania	3,034	15.1%	1,575	16.2%	1,459	14.2%			
	Luxembourg	276	1.4%	88	0.9%	188	1.8%			
	Latvia	121	0.6%	79	0.8%	42	0.4%			
	Malta	321	1.6%	107	1.1%	214	2.1%			
	Netherlands	335	1.7%	184	1.9%	151	1.5%			
	Poland	456	2.3%	261	2.7%	195	1.9%			
	Portugal	1,363	6.8%	508	5.2%	855	8.3%			
	Romania	1,831	9.1%	810	8.3%	1,021	9.9%			
	Sweden	917	4.6%	370	3.8%	547	5.3%			
	Slovenia	498	2.5%	289	3.0%	209	2.0%			
	Slovakia	655	3.3%	332	3.4%	323	3.1%			
	Slovakia	528	2.6%	218	2.2%	310	3.0%			

Table 1. Distribution of the study population in total and by sex for individuals having DM according to demographic, socioeconomic, and lifestyle variables. *p-values in bold indicate significance after Bonferroni correction. χ^2: chi-square. BMI: body mass index (kg/m^2).

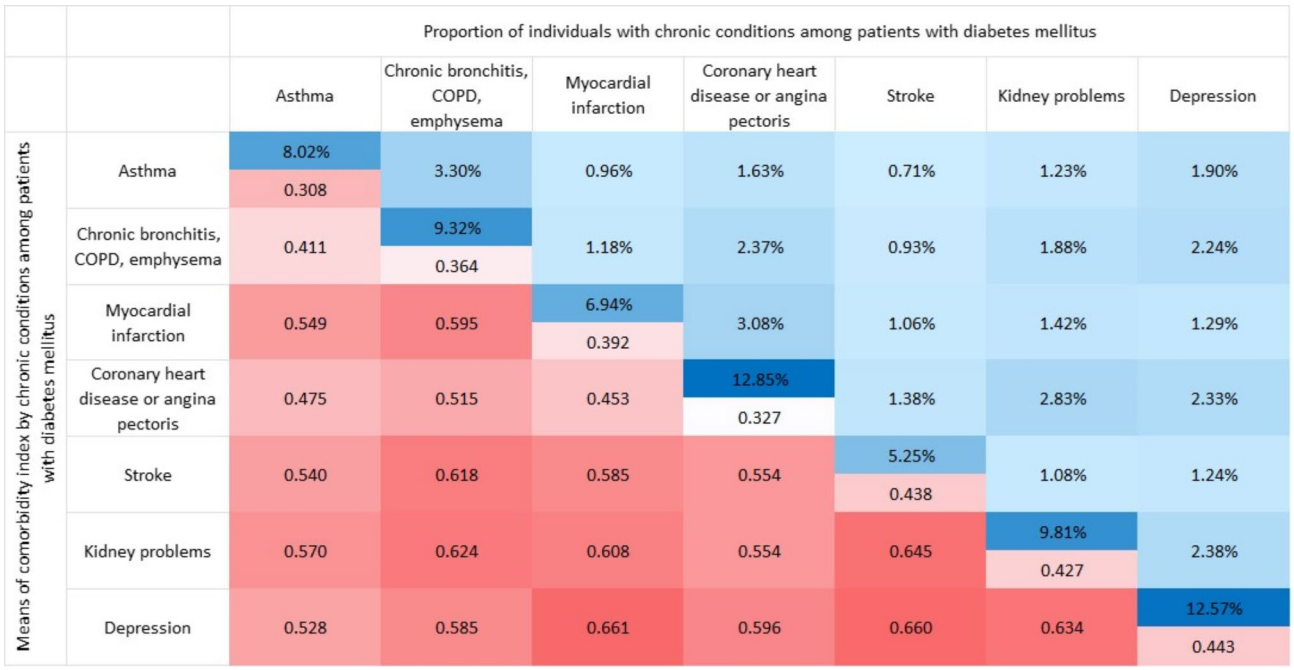

Fig. 1. Proportion of individuals and means of comorbidity index by chronic conditions among individuals with diabetes mellitus.

		Estimated Coefficient ($\widehat{\beta}$)	95% Confidence Interval		*p*-value
			Lower bound	Upper bound	
Sex (ref. Male)	Female	0.044	0.016	0.071	**0.002**
Age group (ref. 25–34)	35–44	0.084	-0.065	0.232	0.271
	45–54	0.167	0.033	0.301	**0.015**
	55–64	0.072	-0.058	0.202	0.277
	65–74	-0.040	-0.172	0.092	0.549
	75+	0.091	-0.042	0.223	0.181
Education (ref. primary)	Secondary	-0.072	-0.107	-0.037	**<0.001**
	Higher	-0.085	-0.130	-0.040	**<0.001**
Employment status (ref. employed)	Unemployed	0.227	0.143	0.311	**<0.001**
	Other	0.331	0.284	0.377	**<0.001**
Income quintile (ref. 1st quintile)	2nd quintile	-0.082	-0.120	-0.044	**<0.001**
	3rd quintile	-0.107	-0.147	-0.066	**<0.001**
	4th quintile	-0.121	-0.165	-0.077	**<0.001**
	5th quintile	-0.154	-0.204	-0.105	**<0.001**
Residence (ref. urban)	Rural	-0.028	-0.057	0.001	0.059
Smoking (ref. non-smoker)	Smoker	-0.026	-0.064	0.012	0.180
Fruit (ref. daily)	1–6 times a week	0.018	-0.015	0.051	0.282
	Less than once a week or never	0.102	0.045	0.160	**<0.001**
Vegetable (ref. daily)	1–6 times a week	0.014	-0.016	0.044	0.354
	Less than once a week or never	0.251	0.186	0.316	**<0.001**
BMI (ref. normal/underweight)	Overweight	-0.022	-0.057	0.013	0.219
	Obese	0.081	0.044	0.117	**<0.001**
Physical activity (ref. none or one day)	Two days or more	-0.354	-0.383	-0.324	**<0.001**
Intercept		-1.472	-2.944	-1.317	**<0.001**
		Variance	**Standard deviation**		
Random effect (country)		0.026	0.163		
AIC		-28976.4			
BIC		-28770.8			
Log-Likelihood		14514.2			

Table 2. The association between comorbidity index and demographic, socioeconomic, and lifestyle variables for the people with diabetes mellitus (DM), using mixed beta regression analysis. Significant differences are shown is bold. BMI: body mass index (kg/m^2).

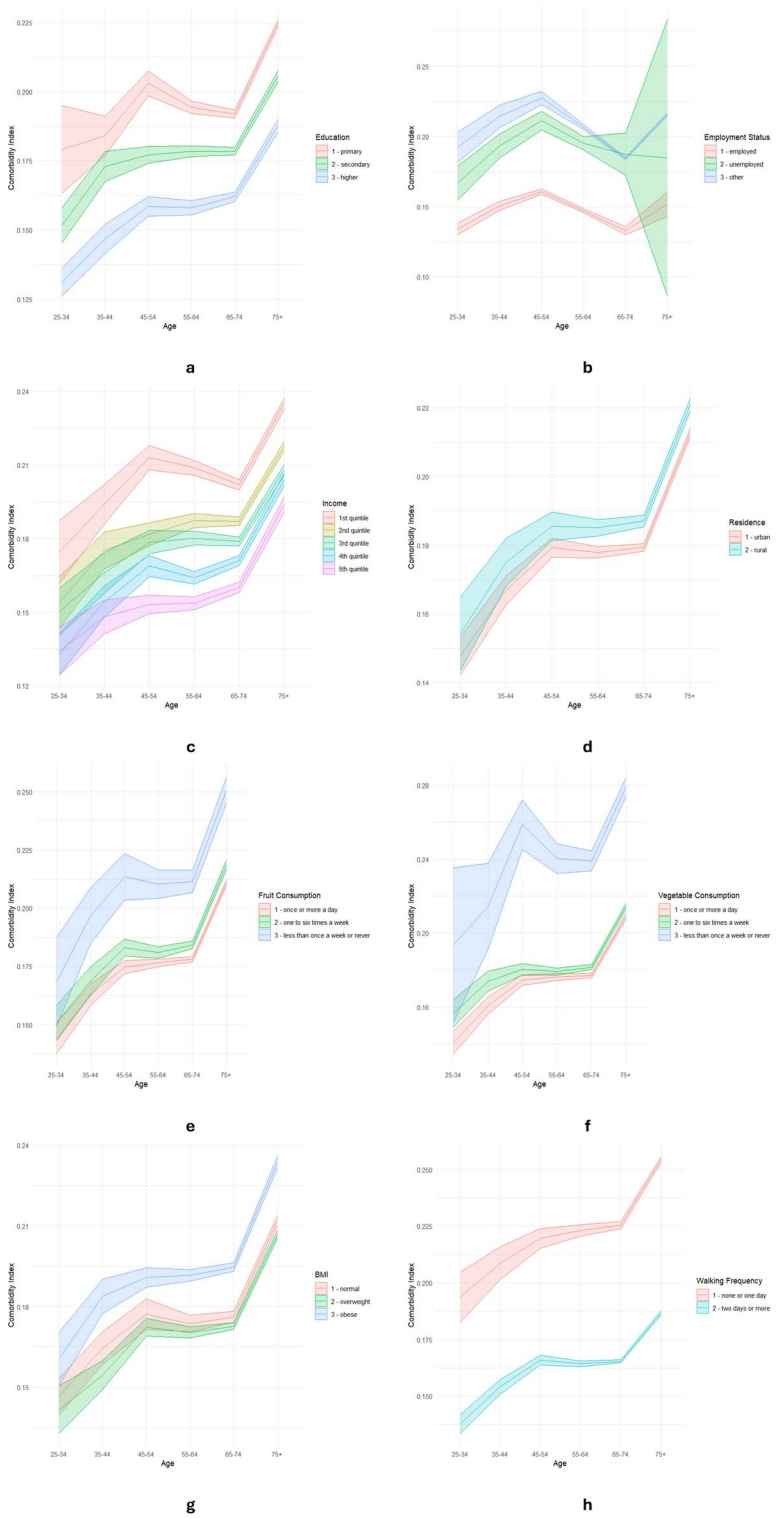

Fig. 2. Estimated values (with 95% confidence interval) of the comorbidity index across age groups and by different socioeconomic (**a**–**d**) and lifestyle (**e**–**h**) factors.

education, unemployed or another labor status, lower income, rural residence, as well as lifestyle factors including obesity, less than two days of physical activity per week, and less frequent fruit and vegetable consumption. The wide confidence interval for unemployment in older age likely reflects the limited number of retired persons.

The comorbidity index for NUTS2 regions was calculated as a mean, represented in Fig. 3. According to the general pattern, the comorbidity burden was higher in Eastern and Southern European countries. The highest comorbidity index was observed in Calabria (Italy), followed by Lubuskie (Poland), and the lowest

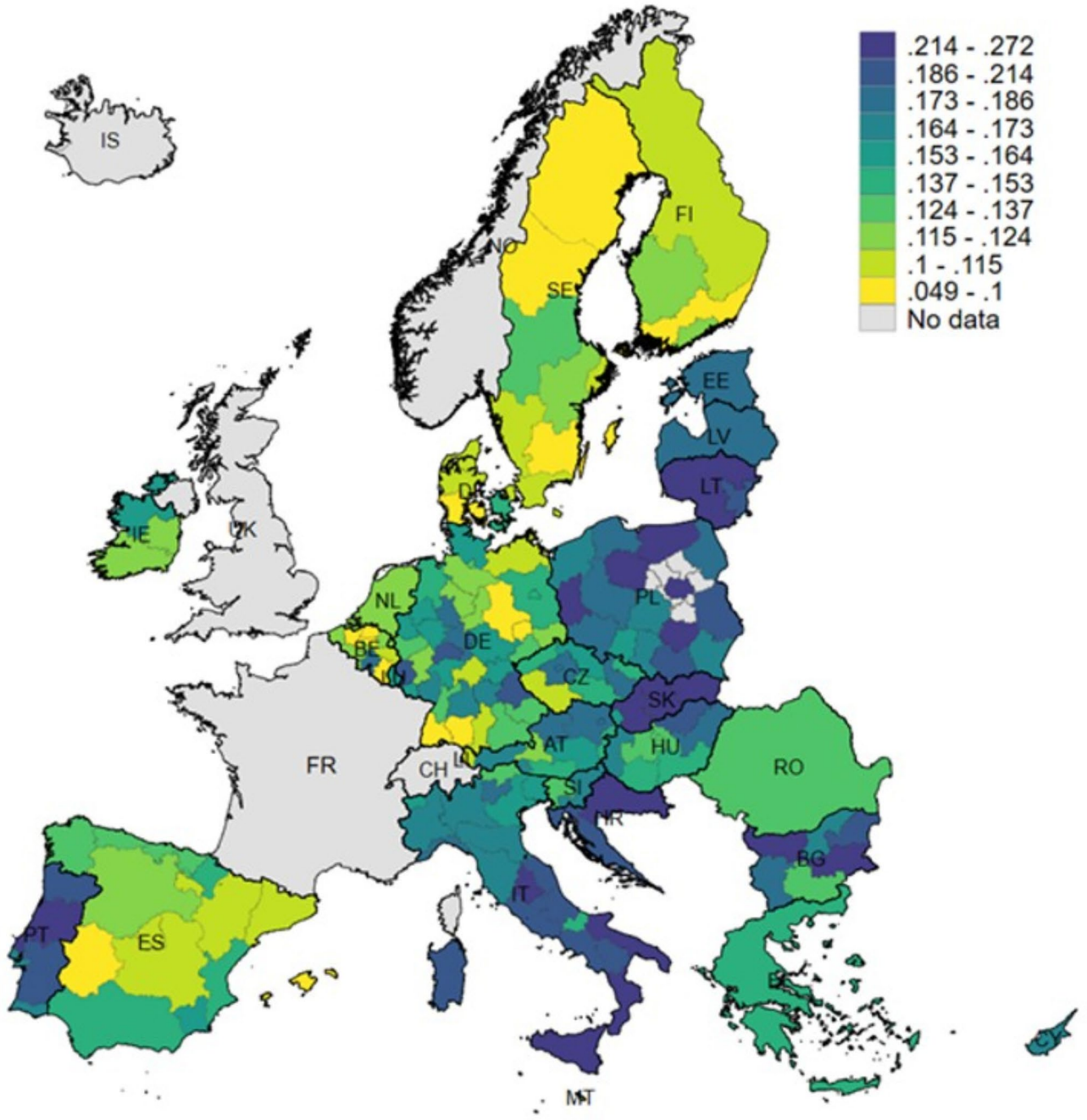

Fig. 3. Comorbidity index by NUTS 2 regions in the European Union 26 member states. Data on France were not available.

was observed in Antwerp (Belgium), followed by Övre Norrland (Sweden). In Eastern and Southern Europe, regions in Bulgaria, Croatia, Lithuania, Poland, and Slovakia exhibited higher comorbidity indices. Lithuania's Vidurio ir vakaru Lietuvos region was also among the highest, with a comorbidity index of 0.247. Similarly, Kontinentalna Hrvatska in Croatia had a relatively high index of 0.245. In Poland, regions such as Kujawsko-Pomorskie, Lubuskie, and Warminsko-Mazurskie also showed elevated comorbidity, with indices ranging from 0.224 to 0.269. Bulgaria's Severozapaden region had a high comorbidity index of 0.233. In Slovakia, the Stredné Slovensko region shared a similar comorbidity level with an index of 0.245, while Východné Slovensko followed with an index of 0.216. Italy and Portugal also had regions with elevated indices. In Italy, Calabria and Sicilia had the highest comorbidity indices in the country, at 0.272 and 0.244, respectively. This contrasts with neighboring regions. In Portugal, regions such as Centro and Região Autónoma dos Açores displayed significant comorbidity indices, with Centro at 0.243 and Açores at 0.215.

Discussion

It is essential to study real-world comorbidity burden to gain a more comprehensive understanding of how multiple chronic conditions interact and affect individuals, particularly in relation to social determinants of health[25]. This approach permits the identification of patterns of comorbidities that vary across different populations and regions. This, in turn, enables the implementation of targeted interventions that address the complex needs of patients and reduce the health inequalities associated with socioeconomic factors.

The comorbidity burden index, developed using the methodology of Andreella and coauthors[13] with large population-based data and GBD disability weights, proved to be an effective tool for measuring comorbidity patterns and identifying high-risk groups at the sub-national level and across EU member states.

Our findings confirm that lower SES individuals experience higher rates of DM complications due to several interrelated factors. Several studies have suggested that the prevalence of multimorbidity increases with age[26,27]. In this study, the value of the comorbidity index increased with age, with a particular increase after age 65 for all categories of risk factors. Still, the difference between sub-groups was slightly greater in older age groups. This suggests that addressing the risk factors and promoting healthy behaviours early may be beneficial in reducing the burden of DM comorbidity in older age.

We found that socioeconomic status and health behavior are significant determinants of comorbidity prevalence. Our study found that SES inequalities exist in the prevalence of DM comorbidities, with those with lower SES having a greater burden of multiple chronic conditions, which is consistent with prior studies[28–31]. A substantial body of research has consistently demonstrated a robust correlation between lower SES and a higher prevalence of T2DM[32] and its associated comorbidities[33] due to several factors, including limited access to healthcare, a higher prevalence of unhealthy food options, and lower health literacy. Those with lower income and educational levels are not only more likely to develop T2DM but also to experience more severe complications[34] and comorbid conditions than those with higher SES[35]. The educational level is highly relevant in terms of diabetes self-management, which plays an important role in the development of associated comorbidities[10]. Furthermore, a study that investigated SES inequalities in the development of T2DM comorbidities across three SES groups (working individuals, nonworking spouses, and pensioners) found that the risk for comorbidities varied by employment status and social roles. However, no clear differences were observed in the development of comorbidities among the different SES groups[10]. Socioeconomic factors can influence healthy behaviors such as diet, physical activity, smoking, and alcohol consumption. It is reasonable to hypothesize that individuals belonging to a lower socioeconomic stratum may be constrained by a lack of resources, which may affect their ability to adopt and maintain healthy lifestyles[30,36]. This may increase their susceptibility to the development of chronic conditions and comorbidities.

The number of people affected by multiple chronic conditions has been increasing worldwide[26,37,38], which may be explained by unhealthy lifestyles such as excess weight, unhealthy diet, and insufficient physical activity, which remain major risk factors for various non-communicable diseases. For example, a pooled analysis of individuals from US and European cohort studies showed an increased risk of cardiometabolic multimorbidity with increasing BMI, ranging from a twofold increase in overweight individuals to a more than tenfold increase in severely obese people[39]. In this study, the comorbidity index was substantially higher among those with lower physical activity levels, unhealthy diets, and obesity. A previous study has also emphasized the prominent role of physical activity among risk behaviours in multimorbidity, suggesting that targeting physical activity can majorly impact health[29]. However, others have also suggested the possibility of a bidirectional relationship between physical activity and comorbidities, as functional impairment may affect the ability to engage in recommended physical activity[29,40]. Importantly, DM alone does not inherently limit one's capacity to participate in physical activities, as many individuals with DM can engage in regular exercise without significant functional impairment[41].

We found that several sub-regions of Eastern and Southern European countries are affected by a higher prevalence of comorbidities. Similarly, a higher prevalence of multimorbidity was found in Central and Eastern European countries by a study using SHARE data[26]. Socioeconomic disparities may contribute to the higher comorbidity burden observed in these countries. Previous studies found an association between geographic deprivation and multimorbidity prevalence[42]. Such findings have important policy implications. It is recommended that policymakers prioritize interventions that target geographical deprivation and enhance access to healthcare and resources for low SES populations to mitigate the effects of coexisting conditions.

To our knowledge, this is the first large population-based study to provide a detailed analysis of the comorbidity burden associated with DM, utilizing the comorbidity index according to the methodology proposed by Andreella and coauthors[13] and considering the severity of comorbid conditions, which is usually ignored in studies on comorbidity burden. However, we acknowledge some limitations of the study. First, data were unavailable for all countries, specifically France. All data (including the presence of DM and comorbid conditions, as well as behaviors) are based on self-reported answers, which can be subject to recall bias and social desirability bias and may lead to overestimating the prevalence or severity of certain diseases. Cross-sectional data cannot be used to make causal inferences. In addition, the list of chronic diseases in the EHIS is limited. Therefore, we could not consider all relevant health conditions when calculating the comorbidity index. Several chronic conditions, including high blood pressure and high blood lipids, which are common conditions in people with DM, were not in our list of comorbidities when constructing the comorbidity index due to the unavailability of disability weights in the GBD study 2019. Due to these limitations, the calculated comorbidity index may underestimate the actual disease burden. Detailed physical activity data was unavailable for several countries; walking was the only available one and was considered a measure of physical activity. Participants with missing data were excluded, which may limit our findings' generalisability. The EHIS data did not allow for stratification by type of DM and separate analysis of T1DM and T2DM, although there are significant differences

in risk factors, age at onset, and comorbidities. However, it seems reasonable to assume that the predominant form of DM in the adult population is type 2, and thus, in our study.

Conclusion

In this population-based study of individuals with DM living in 26 EU member states, we show that the comorbidity index has the potential to identify regions with the highest disability burden and subpopulations characterized by certain SES and health behaviors. The study also revealed a high prevalence of comorbidity in the working age population living with DM. The results of this study suggest that socioeconomic inequalities, lifestyles, and health behaviors should be considered when developing policies to manage comorbidities and reduce the burden of DM. Our findings may help to identify high-risk populations and target lifestyle factors for interventions that may have the greatest impact on the health of people living with DM.

Data availability

Microdata of EHIS 2019 are available from Eurostat upon request (https://ec.europa.eu/eurostat), project RPP 266/2020-LFS-EHIS. The contact person of the database used in our study is Orsolya Varga (varga.orsolya@med.unideb.hu).

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References

1. Valderas, J. M., Starfield, B., Sibbald, B., Salisbury, C. & Roland, M. Defining comorbidity: Implications for understanding health and health services. *Ann. Fam Med.* **7**, 357–363 (2009).
2. Dunn, R., Clayton, E., Wolverson, E. & Hilton, A. Conceptualising comorbidity and multimorbidity in dementia: a scoping review and syndemic framework. *J. Multimorb Comorb* **12**, (2022).
3. Texts adopted - Prevention, management and better care of diabetes in the EU on the occasion of World Diabetes Day. - Wednesday, 23 November 2022. https://www.europarl.europa.eu/doceo/document/TA-9-2022-0409_EN.html
4. Martinez-De la Torre, A., Perez-Cruz, F., Weiler, S. & Burden, A. M. Comorbidity clusters associated with newly treated type 2 diabetes mellitus: A Bayesian nonparametric analysis. *Sci. Rep.* **12**, 20653 (2022).
5. Lipska, K. J., Krumholz, H., Soones, T. & Lee, S. J. Polypharmacy in the aging patient: A review of glycemic control in older adults with type 2 diabetes. *JAMA* **315**, 1034–1045 (2016).
6. Struijs, J. N., Baan, C. A., Schellevis, F. G., Westert, G. P. & van den Bos G. A. Comorbidity in patients with diabetes mellitus: Impact on medical health care utilization. *BMC Health Serv. Res.* **6**, 84 (2006).
7. Nowakowska, M. et al. The comorbidity burden of type 2 diabetes mellitus: Patterns, clusters and predictions from a large English primary care cohort. *BMC Med.* **17**, 145 (2019).
8. Long, A. N. & Dagogo-Jack, S. Comorbidities of diabetes and hypertension: Mechanisms and approach to target organ protection. *J. Clin. Hypertens. (Greenwich)*. **13**, 244–251 (2011).
9. Pearson-Stuttard, J. et al. Variations in comorbidity burden in people with type 2 diabetes over disease duration: A population-based analysis of real world evidence. *eClinicalMedicine* 52, (2022).
10. Safieddine, B., Sperlich, S., Beller, J., Lange, K. & Geyer, S. Socioeconomic inequalities in type 2 diabetes comorbidities in different population subgroups: Trend analyses using German health insurance data. *Sci. Rep.* **13**, 10855 (2023).
11. Sarfati, D. How do we measure comorbidity? Cancer and chronic conditions: addressing the problem of multimorbidity in cancer patients and survivors, pp. 35–70. https://doi.org/10.1007/978-981-10-1844-2_2 (Springer, Singapore, 2016) .
12. Monterde, D. et al. Performance of three measures of comorbidity in predicting critical COVID-19: A retrospective analysis of 4607 hospitalized patients. *Risk Manag Healthc. Policy*. **14**, 4729–4737 (2021).
13. Andreella, A., Monasta, L. & Campostrini, S. A novel comorbidity index in Italy based on diseases detected by the surveillance system PASSI and the Global Burden of Diseases disability weights. *Popul. Health Metrics*. **21**, 18 (2023).
14. Lopez, A. D., Mathers, C. D., Ezzati, M., Jamison, D. T. & Murray, C. J. Global and regional burden of disease and risk factors, 2001: Systematic analysis of population health data. *Lancet* **367**, 1747–1757 (2006).
15. Charalampous, P., Polinder, S., Wothge, J., von der Lippe, E. & Haagsma, J. A. A systematic literature review of disability weights measurement studies: Evolution of methodological choices. *Arch. Public. Health*. **80**, 91 (2022).
16. Haagsma, J. A., Polinder, S., Cassini, A., Colzani, E. & Havelaar, A. H. Review of disability weight studies: Comparison of methodological choices and values. *Popul. Health Metrics*. **12**, 20 (2014).
17. Eurostat European Health Interview Survey (EHIS wave 3). Methodological manual. Re-edition, (2020). (2020) edition.
18. Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2019 (GBD 2019) Disability Weights. (2020). https://doi.org/10.6069/1W19-VX76
19. Salomon, J. A. et al. Disability weights for the global burden of disease 2013 study. *Lancet Global Health*. **3**, e712–e723 (2015).
20. Murray, C. J. L. et al. GBD 2010: Design, definitions, and metrics. *Lancet* **380**, 2063–2066 (2012).
21. Global National incidence, prevalence, and years lived with disability for 301 acute and chronic diseases and injuries in 188 countries, 1990–2013: A systematic analysis for the global burden of Disease Study 2013. *Lancet* **386**, 743–800 (2015).
22. Cribari-Neto, F. & Zeileis, A. Beta regression in R. *J. Stat. Softw.* **34**, 1–24 (2010).
23. Brooks, M. et al. *glmmTMB: Generalized Linear mixed models using template model builder*. (2024).
24. Arel-Bundock, V., Greifer, N. & Bacher, E. *Marginaleffects: Predictions, Comparisons, Slopes, Marginal Means, and Hypothesis Tests*. (2024).
25. Álvarez-Gálvez, J. et al. Social inequalities in multimorbidity patterns in Europe: A multilevel latent class analysis using the European Social Survey (ESS). *SSM Popul. Health*. **20**, 101268 (2022).
26. Souza, D. L. B. et al. Trends of multimorbidity in 15 European countries: A population-based study in community-dwelling adults aged 50 and over. *BMC Public. Health*. **21**, 76 (2021).
27. Navickas, R., Petric, V. K., Feigl, A. B. & Seychell, M. Multimorbidity: What do we know? What should we do? *J. Comorb*. **6**, 4–11 (2016).
28. Uddin, J. et al. Socioeconomic disparities in diabetes-concordant comorbidity: National health interview survey, 1997–2018. *Public. Health*. **222**, 160–165 (2023).
29. Suhag, A., Webb, T. L. & Holmes, J. Longitudinal clustering of health behaviours and their association with multimorbidity in older adults in England: A latent class analysis. *PLoS One*. **19**, e0297422 (2024).
30. Shin, A. et al. Association between socioeconomic status and comorbidities among patients with rheumatoid arthritis: Results of a nationwide cross-sectional survey. *Rheumatology* **58**, 1617–1622 (2019).

31. Schiøtz, M. L., Stockmarr, A., Høst, D., Glümer, C. & Frølich, A. Social disparities in the prevalence of multimorbidity – A register-based population study. *BMC Public. Health.* **17**, 422 (2017).
32. Hwang, J. & Shon, C. Relationship between socioeconomic status and type 2 diabetes: Results from Korea National Health and Nutrition Examination Survey (KNHANES) 2010–2012. *BMJ Open.* **4**, e005710 (2014).
33. Hill-Briggs, F. et al. Social determinants of health and diabetes: A scientific review. *Diabetes Care*. **44**, 258–279 (2020).
34. Tatulashvili, S. et al. Socioeconomic inequalities and type 2 diabetes complications: A systematic review. *Diabetes Metab.* **46**, 89–99 (2020).
35. Lam, A. A., Lepe, A., Wild, S. H. & Jackson, C. Diabetes comorbidities in low- and middle-income countries: An umbrella review. *J. Glob Health* **11**, 04040 .
36. Meader, N. et al. A systematic review on the clustering and co-occurrence of multiple risk behaviours. *BMC Public. Health.* **16**, 657 (2016).
37. Lai, F. T. T. et al. Sex-specific intergenerational trends in morbidity burden and multimorbidity status in Hong Kong community: An age-period-cohort analysis of repeated population surveys. *BMJ Open.* **9**, e023927 (2019).
38. van Oostrom, S. H. et al. Time trends in prevalence of chronic diseases and multimorbidity not only due to aging: Data from general practices and health surveys. *PLOS ONE*. **11**, e0160264 (2016).
39. Kivimäki, M. et al. Overweight, obesity, and risk of cardiometabolic multimorbidity: Pooled analysis of individual-level data for 120 813 adults from 16 cohort studies from the USA and Europe. *Lancet Public. Health*. **2**, e277–e285 (2017).
40. Calderón-Larrañaga, A. et al. Multimorbidity and functional impairment—bidirectional interplay, synergistic effects and common pathways. *J. Intern. Med.* **285**, 255–271 (2019).
41. Mortensen, S. R. et al. Determinants of physical activity among 6856 individuals with diabetes: A nationwide cross-sectional study. *BMJ Open. Diabetes Res. Care*. **10**, e002935 (2022).
42. Pathirana, T. I. & Jackson, C. A. Socioeconomic status and multimorbidity: A systematic review and meta-analysis. *Aust. N. Z. J. Public Health*. **42**, 186–194 (2018).

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Author contributions

N.K., N.M. and O.V. conceptualized and designed the study. Data were curated by N.K. and N.M. N.K. and N.M. conducted the statistical analyses. N.K. and N.M. performed data visualization. N.K. and N.M. wrote the original draft. O.V., L.M., A.A. and S.C. reviewed and edited the manuscript. All authors read and approved the final manuscript.

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Declarations

Competing interests

The authors declare no competing interests.

Additional information

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