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Title

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Identifying multimorbidity clusters with the highest primary care use: 15 years of evidence from a multi-ethnic metropolitan population

Abstract

Background: People with multimorbidity have complex healthcare needs. Some co-occurring diseases interact with each other to a larger extent than others and may impact differently on primary care use.

Aim: To assess the association between multimorbidity clusters and primary care consultations over time.

Design and setting: A retrospective longitudinal (panel) study design was used. Data comprised electronic primary care health records of 826,166 patients registered at GP practices in an ethnically diverse, urban setting in London between 2005 and 2020.

Method: Primary care consultation rates were modelled using Generalised Estimating Equations. Key controls included the total number of LTCs, five multimorbidity clusters, and their interaction effects, ethnicity, and polypharmacy (proxy of disease severity). Models were also calibrated by consultation type and ethnic group.

Results: Individuals with multimorbidity use two to three times more primary care services than those without multimorbidity (IRR=2.3, 95% CI:2.29-2.32). Patients in the alcohol dependency, substance dependence, and HIV cluster have the highest rate of increase in primary care consultations as additional LTCs accumulate, followed by the mental health cluster (anxiety and depression). Differences by ethnic group are observed, with the largest impact in the chronic liver disease and viral hepatitis cluster for individuals of Black or Asian ethnicity.

Conclusion: This paper identifies multimorbidity clusters with the highest primary care demand over time as additional LTCs develop, differentiating by consultation type and ethnicity. Targeting clinical practice to prevent multimorbidity progression for these groups may lessen future pressures on primary care demand by improving health outcomes.

Key words

Primary health care, multimorbidity, long-term conditions, clusters, ethnicity, longitudinal analysis

How this fits in

Clinical care for patients with multimorbidity is complex. Understanding which combinations of long-term conditions result in the highest primary care use may inform the targeting of disease prevention and care integration efforts. This paper identifies the clustering of alcohol dependence, substance dependence, HIV, and also the clustering of mental health conditions as groups associated with the highest increases in primary care

demand as additional LTCs develop over time. The first estimates of the impact of multimorbidity on primary care consultations across ethnic groups are also provided.

Introduction

Preventing and managing multimorbidity—the co-occurrence of two or more conditions— is challenging for patients, health care providers, and policy makers (1–4). Multimorbidity increases with, but it is not confined to old age (5,6), with prevalence of 33% among middle to older aged adults (37-73 years) in the UK (7). People with multimorbidity often experience worse health outcomes (8–12) and use more health services (13–15); over half of all consultations to GPs in the UK are for multimorbid patients (16). The clinical heterogeneity of multimorbid patients is broad (1) and some co-occurring diseases interact, changing healthcare costs compared with treating each condition separately (8,17). Calls urge a transitioning of the health system from specialism in single-diseases to patient-focussed, cluster-medicine delivery that integrates specialist and generalist care. Research directed at understanding the clustering and sequencing of disease, and the health and economic impact of multimorbidity, with a view to determining key drivers and efficient interventions is needed (2,4).

Most analyses of multimorbidity and primary care use have not been guided by conceptual frameworks (14) and may disregard relevant confounding variables. While studies have categorised multimorbid patients by disease cluster, none have included clinical complexity, such as the number and severity of diseases, within the cluster analysis or the impact of different services offered in GP practices (18). Disease severity is important as individuals in the same disease cluster may have unique care needs depending on how active their conditions are (1,19–21). Part of the complexity behind multimorbidity lies in understanding social factors that enable patients to use health services such as income or ethnicity. Differences in multimorbidity composition and prognosis across ethnic groups have been documented (22–24), but whether the impact of multimorbidity on primary care needs is magnified for certain ethnic groups remains unknown (14). Morbidities tend to accumulate within individuals over time(25) but relatively few analyses use longitudinal data(14,26). A richer conceptual framework, along with a longitudinal study design, would allow more accurate predictions of utilisation. It should enable health care systems to better optimise targeting of preventive care and disease management services.

The aim of this paper is to assess the association between multimorbidity clusters and primary care consultations over time. Based on a 15-year primary care dataset, a novel conceptual framework and disease clusters identified by Bisquera and colleagues using the same sample (27), it pinpoints clusters with the highest uses of primary care services, by type and adjusted for a proxy measure of disease severity.

Method

Study design, setting, and data

A retrospective longitudinal (panel) study design is used, based on anonymised electronic primary care health records from the Lambeth Data Net. Lambeth, an inner-city borough in south London, contains an urban, deprived, and multi-ethnic population. The study sample includes 826,166 people 18 years and above (covering 5,243,478 person years) who were registered to one of 41 general practices in Lambeth between 1 April 2005 and 31 March 2020. These months align with the Quality and Outcomes Framework (QOF) reporting schedule (28), intended to standardise the delivery of primary care.

Variable selection and specification

Annual primary care consultations per patient per year (April 1st to March 31st) are categorised into 14 service types; total consultations, administrative consultations, and 12 combinations of 4 modes of delivery (face-to-face, telephone, home visits, and electronic—including email, telemedicine, and text messages) and 3 provider types (GP, nurse, and other healthcare professional or unspecified clinical—mainly healthcare assistants, physiotherapists, occupational therapist, and pharmacists) (the classification of consultation types into these categories is available upon request).

Multimorbidity is defined as having two or more of 32 long term conditions (LTCs) (**Table S1**)(29).
The choice of independent variables is guided by Andersen's widely used (revised) conceptual framework of health care utilisation (30) and the interrelatedness of comorbidity framework (31,32) (**Figure S1**). Zulman and colleagues postulated that clinical complexity in multimorbidity is directly influenced by the total number of conditions, how comorbidities relate to each other (comorbidity interrelatedness), and their characteristics (e.g., symptom intensity and disease severity). The impact of the total number of conditions on clinical complexity may be moderated by their interrelatedness. These four components are represented in this study by the total number of LTCs, five LTC clusters reported by Bisquera et al. (27) as a measure of LTC interrelatedness, polypharmacy (defined as being prescribed eight or more medications in different British National Formulary (BNF) subgroups within a year) as a proxy of disease severity, and an interaction term between the number of LTCs and the clusters. The five LTC clusters are A) anxiety and depression (*Mental health+*); B) heart failure, Parkinson's disease (PAD), osteoporosis, atrial fibrillation, coronary heart disease (CHD), chronic kidney disease (CKD), stroke or transient ischemic attack (TIA), and dementia (*Cardiovascular+*); C) osteoarthritis,

cancer, chronic pain, hypertension and diabetes (*Pain+*); D) chronic liver disease and viral hepatitis (*Liver+*); E) alcohol dependence, substance dependence, and HIV (*Dependence+*). These groups were identified using Multiple Correspondence Analysis, a statistical technique to analyse clustering of multimorbidity (33,34), and they capture conditions that are as correlated as possible among themselves but not with other groups in the data. The connection reported in previous studies between cardiometabolic diseases and chronic pain; cardiovascular diseases and dementia for older populations are supported in these clusters too (27). Individuals with multimorbidity are assigned to a cluster if more than 50% of their LTCs belonged to that particular group. A range of 'predisposing factors' (30) that also influence primary care consultations were considered, including categories of self-ascribed ethnicity (specified using the ONS 5+1 categories: White, Black (Black/African/Caribbean/Black British), Asian (Asian/Asian British), mixed, other, or unknown), age (specific to each year), and gender. 'Enabling factors' (29) included poverty, measured through the Index of Multiple Deprivation (IMD-2019 at lower super output area level, stratified into local (Lambeth) and national based quintiles(35)), and whether main language spoken was English or not. Age, gender, and ethnicity are self-reported by patients upon registration to a GP practice.

Statistical methods

Number of LTCs, multimorbidity, multimorbidity clusters, polypharmacy and demographic characteristics are summarised across the study period using means and standard deviations for continuous variables and counts and percentages for categorical variables. Distributions of the 14 primary care consultation rates (total and by provider type and mode of delivery) are compared between individuals with and without multimorbidity, across multimorbidity clusters, and ethnic groups, based on Mann-Whitney U test for non-normally distributed variables. Missing data are kept as missing.

The relationship between multimorbidity and primary care consultations is assessed using a series of Generalised Estimating Equations (GEE) with negative binomial distribution and log-link. To account for correlation in repeated measures of the same individual over time, both autoregressive and exchangeable correlation structures are compared using the Quasilikelihood under the Independence model Criterion (QIC). Dependent variables selected include total consultations and six broad modes of delivery and provider types (GP, nurse, other healthcare professional, face-to-face, telephone, and home consultations), with patient year as the unit of analysis. Electronic consultations are limited to descriptive statistics and not modelled separately as

they were not available for the whole study period and numbers are insufficient. Administrative consultations are also excluded from modelling as they may reflect contacts unrelated to health care need.

The main model specification predicts primary care consultations based on the number of LTCs, indicator variables for each multimorbidity cluster, and a polypharmacy indicator. Interaction effects between the count of LTCs and multimorbidity clusters are tested to assess whether the impact of developing one more of the 32 LTCs varies (or is moderated) by multimorbidity clusters, as suggested by our conceptual framework. Models also adjust for ethnicity, age, gender, IMD, and language. Year fixed effects are included in the model as covariates. Due to the interaction term, simple slopes (marginal effect of the number of LTCs across clusters) are computed, and incidence rates generated by exponentiating simple slopes. To illustrate the interaction results, least square means of primary care consultations by number of LTCs and clusters are generated.

As secondary analyses, two additional model specifications are calibrated to facilitate comparisons with previous literature: the first just includes a binary multimorbidity indicator, along with sociodemographic variables; the second adds a polypharmacy indicator to assess the impact of omitting a proxy measure of disease severity on the multimorbidity parameter estimate. For total primary care consultations, the three model specifications are calibrated separately for each ethnic group to assess the variability of multimorbidity effects on primary care consultations by ethnicity.

SAS version 9.4 was used for all analyses. This study is reported using *STROBE* guidelines.

Results

Population

On average, individuals were registered to a Lambeth practice for mean 5.3 years (SD=4.9), 13% (N=106,896) for less than a year, and 11% (N=91,353) for the entire study period. Sixty percent of the study sample were under 40, 12% were 60 or over (mean=40.39, SD=15.62), and 52% were female. Fifty-four percent stated they were of White ethnicity, 14% Black/African/Caribbean/Black British, 6% Asian or Asian British, and 7% mixed; with 18% not stating ethnicity. Fifty one percent considered English as their main language (51%). Most (65%) lived in socially deprived areas (bottom two quintiles of the national IMD index).

Forty one percent had at least 1 LTC, and the prevalence of multimorbidity was 21% over time, with an increasing trend from 16% to 25% across the study period. Of the multimorbid patients, 38% were in the *Mentalhealth+* cluster, 7% the *Cardiovascular+* cluster, 33% the *Pain+* cluster, 1% in the *Liver+* cluster, 2% the Dependence+ cluster, and 19% had combinations of conditions that were not highly correlated with any one particular cluster.

Consultations

Total primary care consultations per year (excluding administrative consultations) and the number of registered patients increased by 69% (1,030,433 to 1,654,076) and 26% (307,157 to 386,238), respectively from 2006 to 2020 (**Table 1**). Average consultation rates (per person-year) increased over the study period, from 3.4 (SD=5.4) to 4.3 (SD=6.7) consultations per patient (**Figure S2**). Individuals of Black ethnicity display a higher and increasing primary care demand over time (**Figure 1**), with a consultation rate in 2020 of 6.03 (SD=7.8) compared to 4.1 (SD=6.4) for White ethnicity individuals.

Individuals with multimorbidity in the unclustered LTCs group showed the highest unadjusted consultation rates in 2020, with an average of 12 primary care consultations (SD=11.8), followed by the *Cardiovascular+* cluster (10.7, SD=10.4) and *Pain+* cluster (10.6, SD=9.4) (**Table 2**). Individuals in the unclustered LTCs group had the highest prevalence of obesity (18.9%), COPD (16.9%), and epilepsy (10.5%) in our sample. The highest rates of home visits were observed in the *Cardiovascular+* cluster. Differences in the number of long-term conditions, % of individuals with polypharmacy, age, and ethnicity are observed across clusters. Among individuals with multimorbidity, those of Black ethnicity (10.3 ,SD=9.5), Asian ethnicity (10.40, SD=10.0), or multiple ethnicities (9.2, SD=9.3) showed higher total primary care consultations rates than individuals of White ethnicity (8.7, SD=9.5).

Main results

The impact of developing one more LTC on primary care consultations varies by multimorbidity clusters ($p<0.0001$ for the number of LTCs*cluster interaction) (**Table 3, model 1**). The highest rate of increase for every type of primary care visit (except for nurses), occurs in the *Dependence+* cluster, followed by the *MentalHealth+* cluster. For nurse primary care consultations, the *Liver+* cluster shows the largest rate of increase when an additional LTC arises. **Figure S3** illustrates the differences in estimated marginal mean rates.

Primary care consultations show a particularly large predicted increase among individuals with complex multimorbidity (three or more LTCs) in the *Dependence+* cluster as additional LTCs accumulate. Regarding the impact of predisposing and enabling factors on primary care use, primary care consultations increase with age, particularly home visits. The total primary care consultation incidence rate is 18% higher among individuals between 60 and 79 years compared to those between 18 and 39 years of age (IRR=1.18, 95% CI 1.18-1.21), and 4.32 times higher for home consultations (IRR=4.32, 95% CI: 4.20-4.45). Females tend to use primary care services more often than males (IRR=1.66, 95% CI: 1.66-1.67 for total consultations), and the most deprived individuals consult slightly more than the least deprived individuals, except for nurse and phone consultations. Individuals of non-White ethnicity (Black, Asian, multiple, or other) are more likely to use primary care services than individuals of White ethnicity, except for home visits. The largest effect is observed among those of Black ethnicity (IRR=1·17, 95% CI:1·16-1·17, for total consultations, and IRR=0·74, 95% CI: 0·73-0·76 for home consultations). Language is also significantly associated with primary care consultations, except for face-to-face visits (**Table S2**).

Models 2 and 3 (**Table 3**), with multimorbidity as a binary indicator, indicate that multimorbidity is associated with an increase in all types of primary care consultation rates, with the largest effect observed for home visits (**Table 3**, model 2: IRR=2.64, 95% CI: 2.63-2.66 for total consultations and IRR=5.47, 95% CI: 5.37-5.58 for home visits). When polypharmacy is added to the model (**Table 3**, model 3), the association with multimorbidity decreases, but remains large (IRR=2.3, 95%CI:2.29-2.32, and IRR=3.83, 95% CI:3.75-3.91 for home visits). The stratification of the total primary care consultations models by ethnicity reveals some variability in the effect of multimorbidity across ethnic groups (from IRR=2.13, 95% CI: 2.11-2.15 for Black ethnicity to 2.49, 95% CI: 2.41-2.57 for "other" ethnicity) (**Table 4**, model 2). The largest rate of increase in total primary consultations when an additional LTC develops is observed in the *Liver+* cluster for individuals of Black or Asian ethnicity, while *Dependence+* remains the cluster with the largest impact among the other ethnic groups (**Table 4**, model 3).

Parameter estimates remained stable when year 2016 was removed from the study sample and when clinic fixed effects were added (results available upon request)**.** A drop in total consultations was observed in 2016 (**Figure S2**), likely due to practice closures with data loss arising as result of transfer.

Discussion

Summary

This study assessed the longitudinal effects of multimorbidity clusters on primary care consultations among an ethnically diverse and, predominantly, working age population in south London between 2005 and 2020. Our findings indicate that the *Dependence+* cluster, followed by the *Mentalhealth+* cluster, show the largest rate of increase when an additional LTC develops for all consultation types except for nurse consultations, where the *Liver+* cluster had the largest impact. Some variability across ethnic groups is reported, with the largest rate of increase on total primary consultations due to an additional LTC in the *Liver+* cluster for individuals of Black or Asian ethnicity, while *Dependence+* remained the cluster with the largest impact among the other ethnic groups.

Comparison with existing literature

Results from the simplest specification—model 1, with presence of multimorbidity—align with previous findings that multimorbidity more than doubles primary care consultations (16). Our cluster results add to the sparse literature on multimorbidity clusters and primary care consultations, and both mirror and challenge existing findings. For example, Zhu et al. found the highest utilisation among individuals in the depression, anxiety, and painful conditions cluster (IRR=3.21, 95% CI: 3.07-3.36), followed by the alcohol, psychoactive substance misuse, and painful conditions (IRR=3.12, 95% CI: 2.83-3.46)(18). These estimates are larger than the current research, which could be explained by differences in study design (cross-sectional), techniques to identify LTC clusters (clustering of individuals rather than LTCs), and model specification (LTC counts and interaction effects were not accounted for in Zhu et al). However, both studies point to alcohol and substance dependence and mental health clusters as important drivers of primary care consultations in patients with multimorbidity. Stokes and colleagues found no clear multimorbidity combinations based on secondary care costs rather than LTC prevalence and co-occurrence (36). This alternative approach to clustering, motivated by directly identifying the most expensive combinations to inform cost-saving interventions, warrants further exploration as an alternative to current clustering methodologies for primary care data.

Strengths and Limitations

Model specification was grounded in two conceptual frameworks, which guided a refined specification of the clinical complexity of multimorbidity and a careful consideration of confounders in econometric analyses. We provided the first analyses of the interplay between disease severity and multimorbidity as well as differences

across ethnic groups. Disaggregating total primary care consultations by provider type and mode of delivery allowed a more nuanced characterisation of the healthcare demand of multimorbid individuals. A unique strength of this paper is the use of a 15-year dataset, rich with an ethnically diverse population, which improves accuracy of parameter estimates due to larger sample variability and allows the exploration of trends over time compared with cross-sectional data.

Results may not be generalisable to rural, less ethnically diverse, or older populations. Other factors that may explain primary care consultations could not be measured, such as social support (e.g., marital status) and further multimorbidity characteristics (clinical dominance or time since diagnosis). Disease severity was measured through polypharmacy, which may fail to capture important aspects of disease progression not always linked to medications such as functional impairment. Primary care use may also increase the probability of diagnosing LTC, therefore is it difficult to determine the direction of causality between the number of conditions and consultations. Additional LTCs may also be diagnosed from the regular monitoring of the index LTC. Finally, recording accuracy may vary across the 32 LTCs, with a likely under-recording of non-QOF conditions.

Implications for research and practice

Understanding the health and social care needs of patients with multimorbidity is required to effectively transition from a single-disease to a cluster-medicine oriented delivery model(37). This research provides evidence in support of this policy goal by identifying disease clusters associated with the highest primary care use, differentiating across consultation types and ethnic groups.

The impact of multimorbidity clusters on total costs including primary, secondary care, and social care remains unknown. Bringing together data across the care continuum is needed to fully characterise the multimorbidity journey and identify LTCs that most commonly lead to the highest multimorbidity clinical complexity, worst health outcomes, and costly care pathways. Little is known about the expected trajectories of health service use by the most prevalent disease clusters as LTCs accumulate, and how these trajectories differ across ethnic groups. Finally, research on the effectiveness and cost-effectiveness of interventions aimed at preventing and improving the management of the multimorbidity journey for individuals at the highest risk of accumulating the most expensive LTCs is needed (38).

Conclusion

This study identified the clustering of alcohol dependence, substance dependence, HIV, and also the clustering of mental health conditions as groups associated with the highest increases in primary care demand as additional LTCs develop. Designing and implementing payment incentives in order to target primary care interventions to these individuals to prevent further acquisition of diseases may improve their health outcomes and reduce future primary care use.

List of abbreviations

LTC = Long term conditions, MM = Multimorbidity, GP = General Practices, GEE= Generalised Estimating Equations, BMI = Body Mass Index, UK = United Kingdom, QOF = Quality Outcomes Framework, CHD=Coronary heart disease, CKD=Chronic kidney disease, COPD=Chronic obstructive pulmonary disease, PAD=Parkinson's disease, Stroke/TIA=stroke or transient ischemic attack, IMD=Index of Multiple Deprivation, IQR= interquartile range, IRR=Incidence Rate Ratio, CR=consultation rate.

Declarations

Funding: The study was supported by a grant from Guy's and St Thomas' Charity (Charity No: 1160316).

Ethics approval: All data were extracted under the terms of a signed data sharing agreement with each practice and with project-specific approval following submission of a data privacy impact assessment, approved by Lambeth Clinical Commissioning Group in 2 November 2017. Information governance approval required 'low number suppression', ensuring that data could not be displayed if the patient number was 10 or less in any given category; in these circumstances, data reporting would state: '≤10 patients'. Separate ethical committee approval was not required (Health Research Authority, 29 September 2017) since all data were fully anonymised for the purposes of research access, and all patient identifiable data had been removed.

Competing interests: The authors declare that they have no competing interests.

Authors' contributions: Marina Soley-Bori: Conceptualization, Methodology, Software, Validation, Formal analysis, Writing - Original Draft, Writing - Review & Editing. **Alessandra Bisquera:** Validation, Writing - Review & Editing. **Mark Ashworth:** Conceptualization, Methodology, Resources, Writing - Review & Editing, Investigation, Supervision, Project administration, Funding acquisition. **Yanzhong Wang:** Writing - Review & Editing. **Stevo Durbaba:** Data curation, Software. **Hiten Dodhia**: Conceptualization, Resources, Writing -

Review & Editing, Investigation, Funding acquisition; **Julia Fox-Rushby:** Conceptualization, Methodology, Resources, Writing - Review & Editing, Investigation, Supervision, Funding acquisition.

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Identifying multimorbidity clusters with the highest primary care use: 15 years of evidence from a multi-ethnic metropolitan population

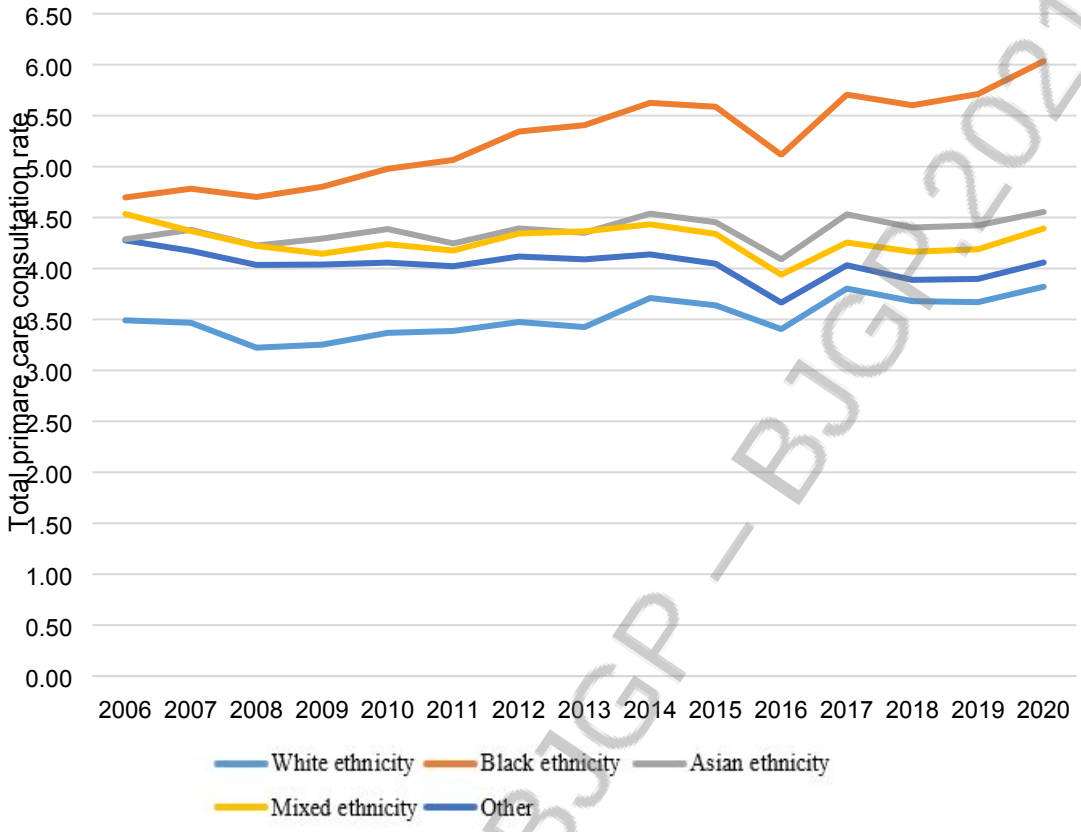
Tables and Figures included in the main body of the manuscript

Table 1. Total primary care consultations, percentage used by individuals with multimorbidity, and consultation rates for the years 2006, 2013, and 2020*

	2006 (N=307,157)			2013 (N=358,427)			2020 (N=386,238)		
	Total	%MM	CR	Total	%MM	CR	Total	%MM	CR
Total consultations	1,030,433	46%	3.4 (5.4)	1,438,958	51%	4.0 (6.3)	1,654,076	56%	4.3 (6.7)
GP face-to-face	530,345	45%	1.7 (3.1)	867,835	51%	2.4 (3.8)	811,053	55%	2.1 (3.4)
GP telephone	42,030	57%	0.1 (0.8)	165,742	56%	0.5 (1.6)	349,127	59%	0.9 (2.3)
GP home	9,821	79%	0.03 (0.4)	12,766	89%	0.04 (0.5)	14,283	95%	0.04 (0.6)
GP electronic	0	.	0	96	63%	0.00 (0.0)	2,079	48%	0.00 (0.1)
Nurse face-to-face	165,059	44%	0.5 (1.6)	248,192	47%	0.7 (2)	214,515	52%	0.6 (1.7)
Nurse telephone	6,011	45%	0.02 (0.2)	7,937	56%	0.02 (0.2)	14,437	54%	0.04 (0.3)
Nurse home	3,507	88%	0.01 (0.4)	2,245	92%	0.01 (0.2)	1,916	95%	0.01 (0.1)
Nurse electronic	0	.	0	1	100%	0.00 (0.0)	87	45%	0.0 (0.0)
Other face-to-face	249,876	43%	0.8 (2.2)	128,150	52%	0.4 (1.3)	175,469	61%	0.5 (1.4)
Other telephone	19,970	49%	0.1 (0.5)	5,274	55%	0.02 (0.2)	69,370	56%	0.2 (0.9)
Other home	3,814	79%	0.01 (0.3)	717	68%	0.00 (0.1)	1,353	95%	0.00 (0.1)
Other electronic	0	.	0	3	67%	0.0(0)	387	46%	0.00 (0.0)
Administrative	116,221	45%	0.4 (1.4)	164,282	47%	0.5 (1.3)	286,255	50%	0.7 (1.6)

Notes:* This table excludes intervening years for simplicity. 2006 includes data from April 2005 to March 2006. 2013 includes data from April 2012 to March 2013, and 2020 includes data from April 2019 to March 2020. Descriptives for all data years (2006-2020) are available upon request. N indicates that number of registered patients in a given year. Total consultations do not include administrative consultations. CR=consultation rates (per-person year). MM=multimorbidity. Mean (SD).

Figure 1. Total primary care consultation rate by ethnicity: 2006-2020



Notes**:** The 2016 drop is likely due to practice closures with data loss arising as result of transfer. Categories of self-ascribed ethnicity include White, Black (Black/African/Caribbean/Black British), Asian (Asian/Asian British), mixed, other, or unknown.

Table 2. Primary care consultation rates and sample characteristics by multimorbidity cluster for year 2020

	Mental health+	Cardio-vascular+	Pain+	Liver+	Dependence+	Unclustered LTCs	No MM
N	67,040	12,017	57,747	1,369	3,299	32,921	651,773
Total consultations	6.6(7.4)	10.7(10.4)	10.6(9.4)	4.8(6.4)	5.3(6.9)	12(11.8)	2.5(4.1)
GP consultations	5.1(6.1)	7.4(8.2)	7.2(7.1)	3.2(4.8)	3.7(5.3	8.6(9.2)	1.8(3.1)
Nurse consultations	0.7(1.6)	1.4(3.5)	1.6(3.1)	0.7(1.7)	0.8(2.6)	1.6(3.8)	0.4(1.1)
Other consultations	0.8(1.9)	1.9(3.4	1.9(3.1)	0.8(2.1)	0.8(2)	1.9(3.4)	0.3(1.1)
Face-to-face consultations	4.7(5.2)	7(6.9)	7.9(6.9)	3.6(4.8)	3.9(5.4)	8.2(8)	1.9(3)
Telephone consultations	1.9(3.4)	3(4.1)	2.5(4.1)	1.1(2.4)	1.3(2.6)	3.5(5.7)	0.6(1.6)
Home consultations	0.0(0.3)	0.7(2.4)	0.2(1.3)	0.0(0.2)	0.0(0.3)	0.3(1.5)	0.0(0.1)
Number of LTCs	2.5(0.7)	3.9(2.1)	3.5(1.6)	2.3(0.6)	2.6(0.9)	4.6(2.1)	0.2(0.4)
% with polypharmacy	4%	24.4%	18.6%	3.6%	3.8%	20.6%	0.6%
Age	39.7 (12.6)	76.1 (15.5)	64 (16.5)	44.6 (11.5)	41.7 (11.2)	55.6 (18.9)	36.9 (12.2)
% White	65.4%	56.5%	43.1%	43.5%	64.2%	60.5%	53.3%

Notes: MM=multimorbidity. *Mental health*+ includes anxiety and depression; *Cardiovascular*+ includes heart failure, PAD, osteoporosis, atrial fibrillation, CHD, CKD, stroke/TIA, and dementia; *Pain*+ includes osteoarthritis, cancer, chronic pain, hypertension and diabetes; *Liver*+ includes chronic liver disease and viral hepatitis; *Dependence*+ includes alcohol dependency, substance dependence, and HIV; *Unclustered LTCs* include: Parkinson Disease, COPD, asthma, IBD, lupus, multiple sclerosis, rheumatoid arthritis, morbid obesity, cognitive and learning disabilities, sickle-cell anaemia, serious mental illness, and epilepsy. Mean (SD) for continuous variables, % for categorical variables. 2020 includes data from April 2019 to March 2020. Consultation rate descriptives are similar across time and are available upon request for all data years.

Table 3. Adjusted incidence rate ratios (IRR) of multimorbidity-related variables by primary care consultation type across three model specifications

	Total			GP			Nurse			Other			Face-to-face			Telephone			Home		
	IRR	95% CI		IRR	95% CI		IRR	95% CI		IRR	95% CI		IRR	95% CI		IRR	95% CI		IRR	95% CI	
Model 1: MM clusters, count LTCs, interaction and polypharmacy																					
Mental health+	1.24	1.23	1.24	1.24	1.23	1.25	1.12	1.11	1.14	1.26	1.24	1.28	1.22	1.21	1.23	1.28	1.26	1.3	1.33	1.29	1.38
Cardiovascular+	1.1	1.09	1.1	1.1	1.1	1.11	1.05	1.04	1.07	1.1	1.08	1.11	1.06	1.06	1.07	1.18	1.17	1.19	1.23	1.21	1.24
Pain+	1.11	1.1	1.11	1.11	1.11	1.11	1.08	1.07	1.09	1.12	1.11	1.13	1.09	1.09	1.09	1.17	1.16	1.18	1.24	1.23	1.25
Liver+	1.22	1.14	1.29	1.2	1.12	1.28	**1.27**	**1.13**	**1.43**	1.23	1.06	1.43	1.2	1.13	1.27	1.37	1.21	1.55	1.2	0.96	1.49
Dependence+	**1.33**	**1.29**	**1.37**	**1.35**	**1.32**	**1.4**	1.14	1.03	1.26	**1.41**	**1.33**	**1.49**	**1.3**	**1.26**	**1.35**	**1.48**	**1.4**	**1.55**	**1.36**	**1.25**	**1.48**
Unclustered LTCs	1.11	1.1	1.11	1.11	1.1	1.11	1.07	1.06	1.08	1.13	1.12	1.14	1.09	1.08	1.09	1.16	1.15	1.16	1.17	1.16	1.18
Model 2: MM only																					
MM (yes)	2.64	2.63	2.66	2.74	2.72	2.75	2.28	2.27	2.32	2.68	2.64	2.69	2.56	2.53	2.59	3.16	3.1	3.19	5.47	5.37	5.58
Model 3: MM and polypharmacy																					
MM (yes)	2.3	2.29	2.32	2.36	2.36	2.39	1.92	1.9	1.93	2.36	2.34	2.39	2.24	2.2	2.25	2.61	2.59	2.64	3.83	3.74	3.9
Polypharmacy (yes)	2.2	2.18	2.21	2.29	2.27	2.3	2.36	2.32	2.39	1.95	1.93	1.97	2.16	2.14	2.16	2.53	2.51	2.56	4.04	3.97	4.1

Notes: MM = multimorbidity. IRR=Incidence rate ratio. 95% CI=95% confidence interval. N=5,243,478 person years, corresponding to 826,166 individuals. Data from April 2005 to March 2020 is used. All models also adjust for age, gender, ethnicity, IMD quintiles, and language. Multimorbidity clusters include: *Mental health+* (anxiety and depression); *Cardiovascular+* (heart failure, PAD, osteoporosis, atrial fibrillation, CHD, CKD, stroke/TIA, and dementia); *Pain+* (osteoarthritis, cancer, chronic pain, hypertension and diabetes); *Liver+* (chronic liver disease and viral hepatitis); *Dependence+* (alcohol dependency, substance dependence, and HIV). The reference category for both MM and MM clusters is not having MM. Categories of self-ascribed ethnicity include White, Black (Black/African/Caribbean/Black British), Asian (Asian/Asian British), mixed, other, or unknown. In model 3, the count of LTCs and MM clusters are included as main effects, along with an interaction between the two variables. Parameter estimates of the main effects cannot be interpreted by themselves anymore because of the interaction. Simple slopes (marginal effect of the continuous variable—number of LTCs—across the different levels of the categorical variable—clusters) are computed instead, and incidence rates generated by exponentiating simple slopes. For example, in model 3, the IRR for each cluster indicates the effect of developing one more LTC for individuals in that specific cluster. For the *Dependence+* cluster, IRR=1.33, so for a one unit increase in the number of LTCs, the incidence rate of primary care consultations increases by 33%, while in the *Cardiovascular+* cluster it increases by 11%.

Table 4. Adjusted incidence rate ratios (IRR) of multimorbidity-related variables predicting total primary care consultations, across three model specifications and ethnicity

	All			White Ethnicity			Black Ethnicity			Asian Ethnicity			Mixed Ethnicity			Other		
Individuals, person-years	826,166	5,243,478		445,460	2,724,461		113,722	960,700		49,893	327,250		31,197	202,016		23,727	144,416	
Model 1: MM clusters, count LTCs, interaction and polypharmacy																		
Mental health+	1.24	1.23	1.24	1.24	1.23	1.25	1.19	1.17	1.21	1.23	1.19	1.27	1.23	1.19	1.26	1.24	1.19	1.29
Cardiovascular+	1.1	1.09	1.1	1.09	1.08	1.1	1.12	1.1	1.13	1.1	1.08	1.12	1.13	1.1	1.16	1.09	1.03	1.14
Pain+	1.11	1.1	1.11	1.11	1.1	1.11	1.11	1.11	1.12	1.1	1.09	1.11	1.11	1.09	1.13	1.13	1.11	1.15
Liver+	1.22	1.14	1.29	1.15	1.05	1.26	**1.4**	**1.28**	**1.52**	**1.41**	**1.16**	**1.71**	1.06	0.78	1.44	1.19	0.97	1.45
Dependence+	**1.33**	**1.29**	**1.37**	**1.33**	**1.28**	**1.37**	1.3	1.21	1.39	1.28	1.04	1.59	**1.33**	**1.18**	**1.5**	**1.42**	**1.2**	**1.68**
Unclustered LTCs	1.11	1.1	1.11	1.1	1.09	1.1	1.12	1.11	1.12	1.11	1.09	1.12	1.11	1.1	1.13	1.14	1.11	1.17
Model 2: MM only	IRR	95% CI		IRR	95% CI		IRR	95% CI		IRR	95% CI		IRR	95% CI		IRR	95% CI	
MM (yes)	2.64	2.63	2.66	2.58	2.56	2.6	2.46	2.43	2.49	2.77	2.71	2.83	2.56	2.5	2.62	2.95	2.85	3.06
Model 3: MM and polypharmacy																		
MM (yes)	2.3	2.29	2.32	2.22	2.21	2.24	2.13	2.11	2.15	2.31	2.27	2.36	2.22	2.17	2.27	2.49	2.41	2.57
Polypharmacy (yes)	2.2	2.18	2.21	2.29	2.28	2.31	2.04	2.02	2.06	2.17	2.14	2.21	2.25	2.2	2.31	2.31	2.23	2.39

Notes: MM = multimorbidity. IRR=Incidence rate ratio. 95% CI=95% confidence interval. N=5,243,478 person years, corresponding to 826,166 individuals. Data from April 2005 to March 2020 is used. All models also adjust for age, gender, ethnicity, IMD quintiles, and language. Multimorbidity clusters include: *Mental health+* (anxiety and depression); *Cardiovascular+* (heart failure, PAD, osteoporosis, atrial fibrillation, CHD, CKD, stroke/TIA, and dementia); *Pain+* (osteoarthritis, cancer, chronic pain, hypertension and diabetes); *Liver+* (chronic liver disease and viral hepatitis); *Dependence+* (alcohol dependency, substance dependence, and HIV). The reference category for both MM and MM clusters is not having MM. Categories of self-ascribed ethnicity include White, Black (Black/African/Caribbean/Black British), Asian (Asian/Asian British), mixed, other, or unknown. In model 3, the count of LTCs and MM clusters are included as main effects, along with an interaction between the two variables. Parameter estimates of the main effects cannot be interpreted by themselves anymore because of the interaction. Simple slopes (marginal effect of the continuous variable—number of LTCs—across the different levels of the categorical variable—clusters) are computed instead, and incidence rates generated by exponentiating simple slopes. For example, in model 3, the IRR for each cluster indicates the effect of developing one more LTC for individuals in that specific cluster. For the *Dependence+* cluster, IRR=1.33, so for a one unit increase in the number of LTCs, the incidence rate of primary care consultations increases by 33%, while in the *Cardiovascular+* cluster it increases by 11%.