## How is the Doctor Feeling?

ICU Provider Sentiment Is Associated with Diagnostic Imaging Utilization

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The judgment of intensive care unit (ICU) providers is difficult to measure using conventional structured electronic medical record (EMR) data. However, provider sentiment may be a proxy for such judgment. Utilizing 10 years of EMR data, this study evaluates the association between provider sentiment and diagnostic imaging utilization. We extracted daily positive / negative sentiment scores of written provider notes, and used a Poisson regression to estimate sentiment association with the total number of daily imaging reports. After adjusting for confounding factors, we found that (1) negative sentiment was associated with increased imaging utilization (p < 0.01), (2) sentiment's association was most pronounced at the beginning of the ICU stay (p < 0.01), and (3) the presence of any form of sentiment increased diagnostic imaging utilization up to a critical threshold (p < 0.01). Our results indicate that provider sentiment may clarify currently unexplained variance in resource utilization and clinical practice.

(1) What is the relationship between ICU provider sentiment and diagnostic imaging utilization?

(2) Is this relationship consistent over the course of ICU length of stay, or does it change over time?

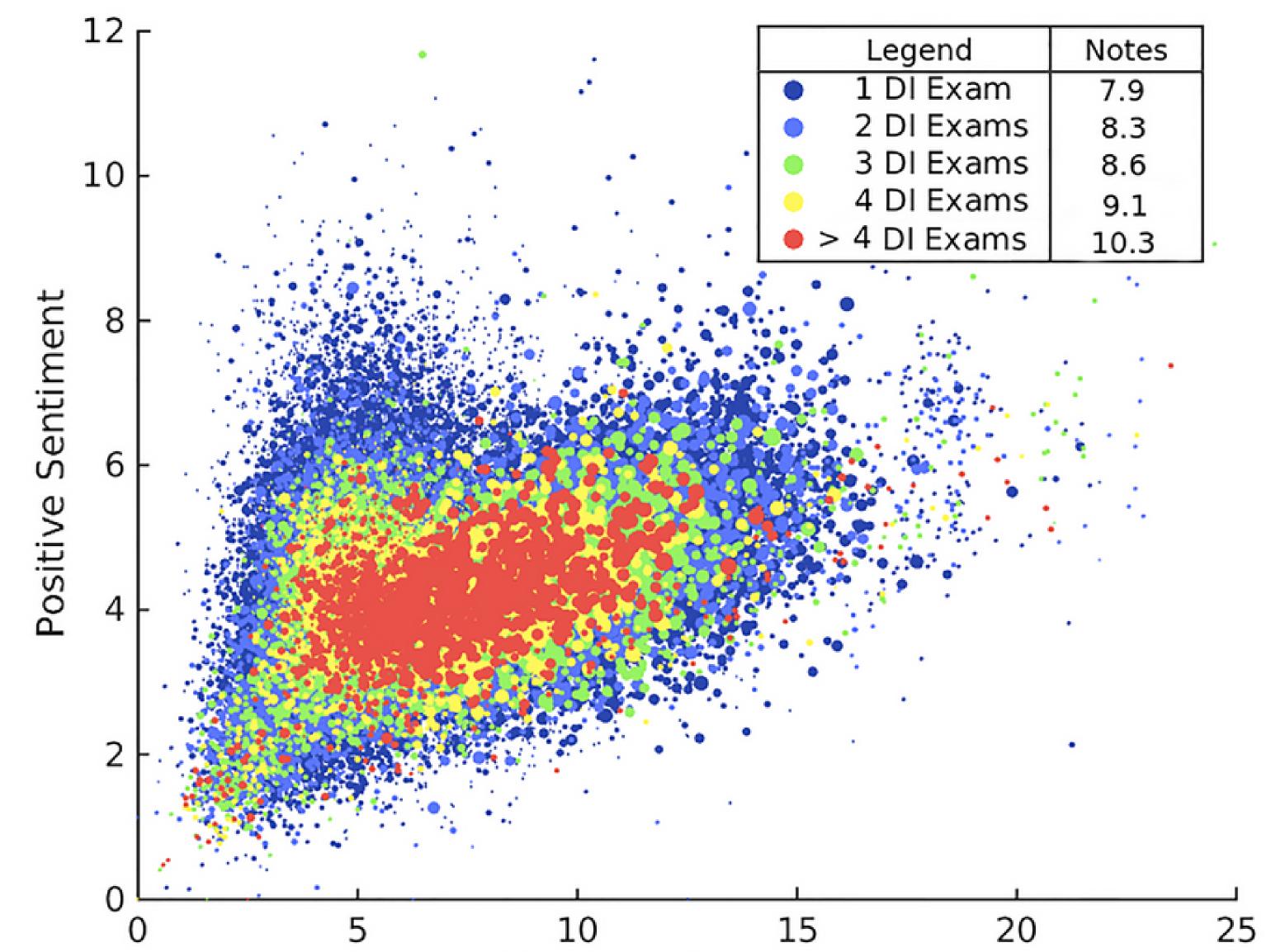
Feature of Interest: The average positive and negative sentiment for all words in provider notes as measured by (sentiwordnet.isti.cnr.it).

Outcome of Interest: The outcome of interest was the total number of daily radiology reports for each ICU patient as a surrogate for the total number of imaging exams.

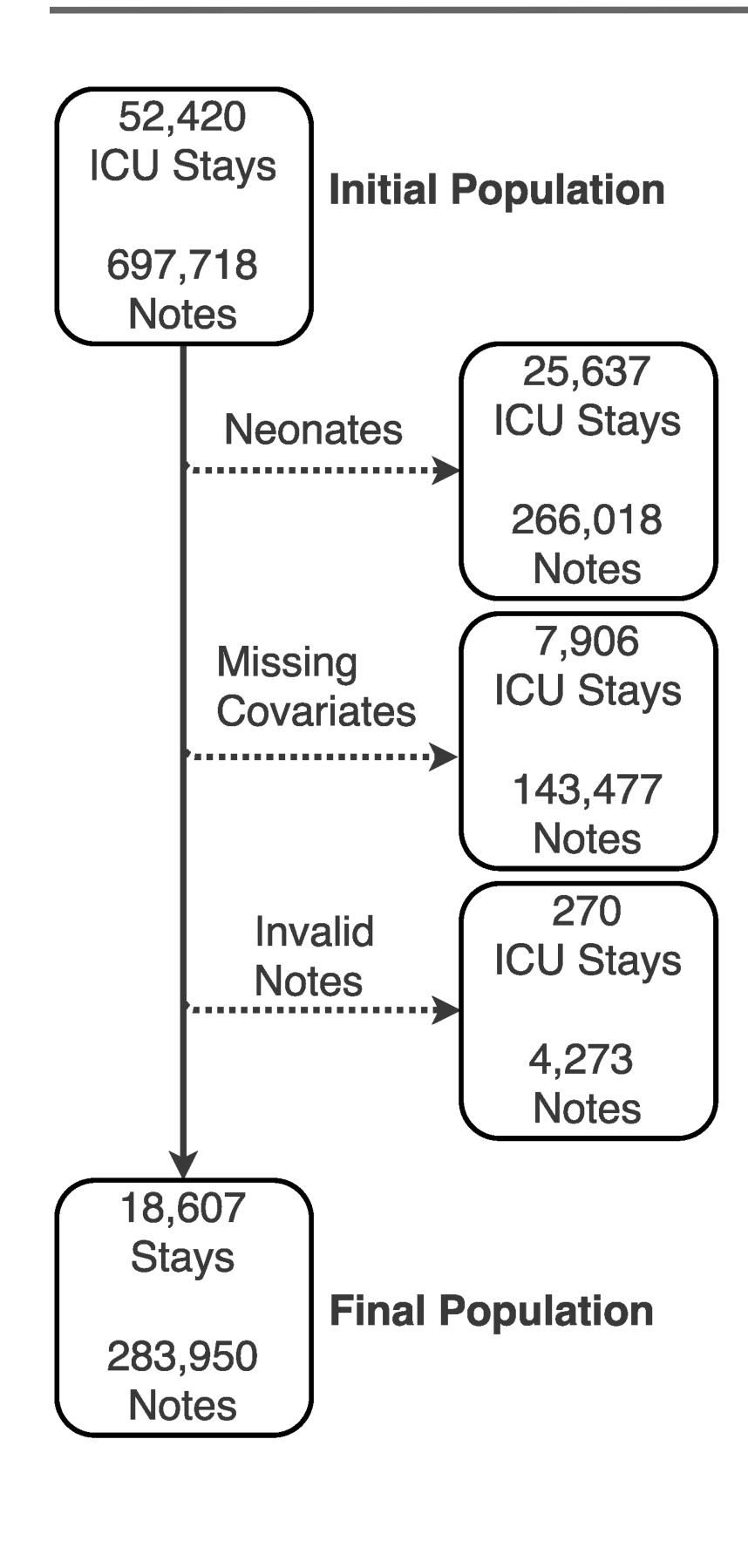
**Confounding Factors:** We extracted a set of continuous and categorical features that were suspected to confound the relationship between provider sentiment and the number of daily imaging exams. The features included: patient age, the Sequential Organ Failure Assessment Score (SOFA), the Elixhauser comorbidity index and the Oxford Acute Severity of Illness Score (OASIS) gender (with female being the reference group) and ethnicity (white, black, Hispanic and other, with white as the reference group). We also included dichotomous indicators for the following conditions: obesity, human immunodeficiency virus infection (HIV), metastatic cancer diagnosis, diabetes and ICU type (with surgical coded as one).

**Data Source**: All data for this study were extracted from the publicly available Medical Information Mart for Intensive Care (MIMIC-III) database (mimic.physionet.org)

Sentiment in Medical Notes. Each point represents a patient's day in the ICU. Colors represent the number of radiological exams received (see legend), while the size of each point indicates the number of provider notes used to compute the sentiment. The average number of notes for each radiological exam level is shown in the figure legend.



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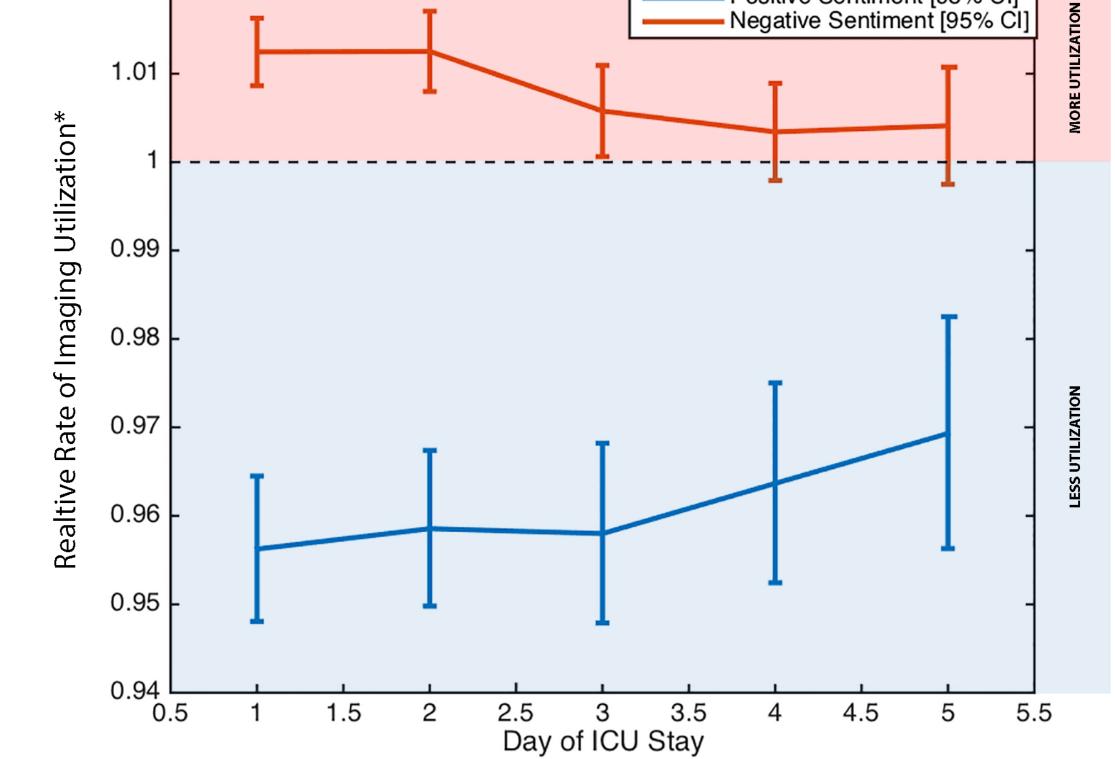
Eligibility **Criteria**: We only considered provider notes from the first five days of patient ICU stay which were of the following types: Consult, General, Nursing, Nutrition, Pharmacy, Physician, Rehabilitation Respiratory. Services We and excluded the notes of all neonatal patients and those missing any of the covariates.

Statistical Methods: A multivariable Poisson regression was used to model the relationship between our features and the number of daily imaging exams while adjusting for potential confounders. Generalized estimating equations (GEE) with a Markov correlation structure were used to fit the models. GEE is useful for our purposes as it accounts for the correlated nature of the observations within each patient, across multiple ICU days and allows for patients to serve as their own controls.

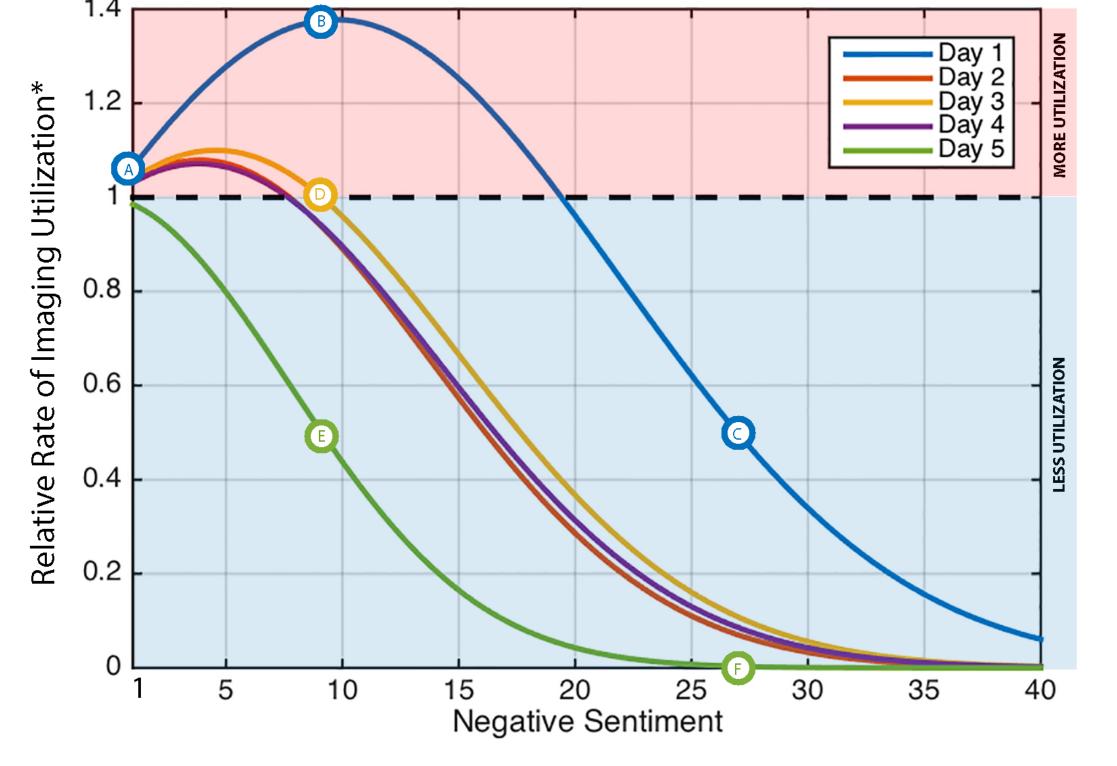
Negative Sentiment

EXAMS PER DAY	1	2	3	4		
Sample Size (Days)	25,455	11,867	4,829	3,548		
CONTINOUS FEATURES (Mean [Standard Deviation])						
Age	65.1 (16)	64.1 (17)	63.2 (17)	61.6 (17.5)		
OASIS	30.6 (9)	30.9 (9)	31.5 (9)	32.2 (9)		
Elixhauser	4.0 (2)	3.9 (2)	3.9 (2.1)	3.9 (2.1)		
SOFA	3.7(3)	4.0 (3)	4.4 (3.2)	4.8 (3.2)		
CATEGORICAL FEATURES (%)						
Diabetes	29.3	27.4	25.5	25.2		
HIV infection	1.2	1.3	1.1	1.1		
Ethnicity - Hispanic	3.6	3.7	3.15	4.2		
Ethnicity - Black	7.3	7.1	6.8	7.9		
Ethnicity - Other	15.6	15.9	16.2	14.2		
Gender (Male)	57.0	58.3	59.0	60.1		
Cancer	5.6	6.1	6.2	5.8		
Obesity	6.7	6.6	6.2	6.8		
ICU Type (Surgical)	17.2	19.8	22.5	22.1		
SENTIMENT FEATURES (Mean [Standard Deviation])						
Negative	6.3 (2.6)	6.4 (2.4)	6.4 (2.3)	6.5 (2.2)		
Positive	4.4 (1.2)	4.3 (0.9)	4.3 (0.8)	4.2 (0.7)		
TABLEI:SUNFEATURESFOPARTITIONEDBYEXAMS.OASIS:ILLNESSSCOFFAILUREASSES	R THE Y THE N OXFOF RE. SOF	PATIEN UMBER ( ND ACU	NT POF DF DAILY FE SEVE	PULATION, IMAGING ERITY OF		

Imaging Utilization over **Time:** Changes in image utilization as a function of daily sentiment over the first 5 days of ICU stay. Curves represent the value of the relative rate of image utilization per unit increase in daily sentiment (y-axis) by ICU day (x-axis).



Imaging Utilization as a Function of Sentiment: The association between negative sentiment (y-axis) and imaging utilization over time for the model with linear and quadratic sentiment terms. Curves represent the estimated relative rate of image utilization per unit negative in increase sentiment.



	eta	Ratio $(\epsilon^{\beta})$	CI (95%)	p-value
CONTINUOUS FEAT	URES			
Age (per year)	-2.2E-3	0.99	0.9896 - 0.9904	< 0.001
OASIS	2.2E-3	1.002	1.0012 - 1.0028	< 0.001
Elixhauser	5.5E-4	1.00	0.0063 - 1.0037	0.74
SOFA	1.8E-2	1.02	1.0178 - 1.0222	< 0.001
CATEGORICAL FEA	TURES			
HIV infection	-6.4E-2	0.94	0.8890 - 0.9910	0.01
Diabetes	-3.4E-2	0.97	0.9547 - 0.9853	< 0.001
Ethn Other*	-2.1E-2	0.98	0.9626 - 0.9974	0.02
Ethn Hispanic*	-7.5E-3	0.99	0.9547 - 1.0253	0.67
Ethn Black*	-4.7E-3	0.99	0.9651 - 1.0174	0.71
Obesity	-8.1E-3	0.99	0.09626 - 1.0174	0.56
Gender (Male)	1.7E-2	1.02	1.0069 - 1.0331	0.01
Cancer	2.2E-2	1.02	0.9947 - 1.0453	0.09
ICU Type (Surgical)	7.4E-2	1.08	1.0637 - 1.0963	< 0.001
SENTIMENT FEATU	RES			
Positive	-4.4E-2	0.96	0.9580 - 0.9620	< 0.001
Negative	9.4E-3	1.01	1.0061 - 1.0139	< 0.001

TABLE II: RESULTS (LINEAR). MULTIVARIABLE POISSON REGRESSION MODEL WITH FEATURES SORTED BY THE STRENGTH OF THE COEFFICIENT, β. SE: STANDARD ERROR. CI: CONFIDENCE INTERVAL. OASIS: OXFORD ACUTE SEVERITY OF ILLNESS SCORE. SOFA: SEQUENTIAL ORGAN FAILURE ASSESSMENT. ETHN.: ETHNICITY . \*RELATIVE TO WHITE.

For questions, or collaboration interests, please email ghassemi@mit.edu