Title
Sociodemographic Contributors To Hypoxia and Hypercapnia-Induced Dyspnea

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Publication Date
2025-07-01

SOCIODEMOGRAPHIC CONTRIBUTORS TO HYPOXIA AND HYPERCAPNIA-INDUCED DYSPNEA

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A capstone project submitted for Graduation with University Honors

May 08, 2025

University Honors

University of California, Riverside

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ABSTRACT

Dyspnea is the subjective sensation of breathing discomfort. This symptom is commonly experienced in hospitalized patients, including those receiving mechanical ventilation. In severe cases, dyspnea has been linked to increased mortality in patients with chronic lung disease as well as poorer clinical outcomes in ICU patients. This outcome may be driven by dyspnea-induced anxiety caused, in part, by a higher work of breathing and carbon dioxide-induced air-hunger. While prior work has provided a detailed understanding of the neurophysiological mechanisms underlying dyspnea, we know little about the drivers of individual variation in how this symptom manifests. Sociodemographic factors may play a role in the psychological mechanisms underlying the sensation of dyspnea, similar to previously reported links between demographic factors and the experience of subjective pain. Therefore, this study aimed to investigate if sociodemographic factors contributed to self-reported dyspnea severity under controlled conditions of modified arterial oxygen and carbon dioxide partial pressures. We hypothesized that higher levels of anxiety related to medical access (including financial concerns) would lead to either blunting or exacerbation of dyspnea severity. To test this hypothesis, we recruited healthy men and women between the ages of 18 and 49. Participants completed a questionnaire examining sources of financial, social, and medical stress. They then completed a dyspnea simulation experiment in which they reported dyspnea severity while breathing controlled oxygen and carbon dioxide tensions to target 6 combinations of end-tidal pCO_2 (45 or 52 mmHg) and inspired oxygen tensions (149, 80, or 68 mmHg). Data demonstrated that individuals who have higher difficulty accessing healthcare are more likely to report higher dyspnea severity, particularly under challenging treatment trials such as 149 mmHg end-tidal pO_2 and 45 mmHg end-tidal pCO_2 ($p=0.0032$, $R=0.48$). This suggests that anxiety related to

accessing medical care may impact subjective sensations of key symptoms linked to disease outcomes, which may lead to underprivileged groups experiencing dyspnea symptoms to a more severe degree than other socioeconomic groups.

ACKNOWLEDGEMENTS

This work was funded by a UCR School of Medicine Dean's Collaborative Seed Grant to ECH. I am deeply grateful for the support from the members of the Heinrich Lab for aiding the study. I would like to express my deepest gratitude to Karapet Mkrtchyan for collecting the data and for guiding me throughout my project. We thank participants for their involvement in the project and for their cooperation throughout the study. Additionally, we thank Anser Qazi, MD for his work in the development of the end-tidal forcing system conducted in the experiment. Lastly, I give my heartfelt appreciation to Dr. Erica Heinrich for the support, encouragement, and mentorship given throughout the duration of this project.

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INTRODUCTION

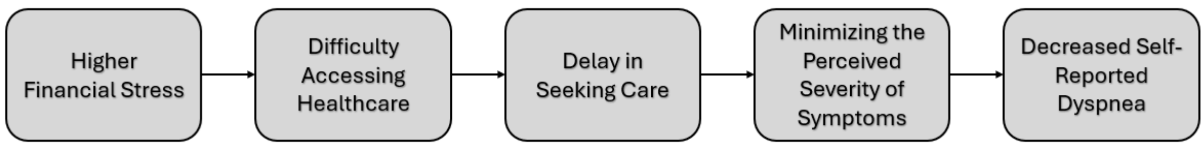
Dyspnea is the subjective sensation of breathing discomfort and is a common symptom in several acute and chronic cardiorespiratory pathologies. Dyspnea, for instance, occurs in panic attacks, asthma exacerbations, and as a result of respiratory infections. It is also difficult to assess dyspnea as it is commonly overlooked in patients. For example, clinicians may attribute chronic dyspnea to exhaustion, limited exercise, or pre-existing conditions, overlooking alternate diagnoses. Similarly, in a hospital setting, patients who can not communicate their discomfort may be overlooked since acute dyspnea does not manifest similarly in all people.

Dyspnea is a multidimensional sensation arising from increased work or effort of breathing, airway resistance, and/or “air hunger” or unsatisfying inspiration. Air hunger is driven in part by input from central and peripheral chemoreceptors which are important for triggering an increase in minute ventilation in response to high carbon dioxide (hypercapnia) or low oxygen (hypoxia) levels in the blood.

Prior research has indicated that sociodemographic factors may be linked to dyspnea during exertion. Currow et al. (2009) reported that patients of lower-income households reported higher rates of breathlessness under exercise-induced dyspnea in a systematic area-sampling survey. Gaffney et al. (2021) also demonstrated lower-income patients scoring higher rates of exercise-induced dyspnea and reporting higher rates of dyspnea-centered conditions such as asthma in surveys. In addition, dyspnea severity disproportionately impacts patients in low socioeconomic environments. Patients with lower income are more likely to be exposed to dyspnea-inducing conditions such as air pollution, cigarettes, hazardous work conditions, and other factors (Gaffney et al., 2021). Despite this preliminary work, there is a gap in research investigating the mechanisms underlying this link between dyspnea onset and sociodemographic factors. We investigated this gap based on the following proposed mechanism (**Figure 1**).

Figure 1

Proposed mechanism for sociodemographic conditions affecting self-reported dyspnea severity



In addition to possible differences in the prevalence of dyspnea-related conditions, low income individuals may delay hospitalization or seeking healthcare due to financial anxieties or simple lack of care access, thereby delaying treatment for their symptoms until such complications are unbearable (Ikram & Pillay, 2022, p. 68). As dyspnea is a symptom that often leads patients to seek care, variation in how different sociodemographic groups perceive dyspnea may contribute to delays in accessing care, potentially leading to disparities in clinical outcomes. For example, Ikram & Pillay (2022) demonstrated that patients with lower oxygen content in the blood who experienced a longer disease progression prior to hospitalization experienced poorer clinical outcomes, including higher rates of mortality.

The goal of the study was to determine if sociodemographic factors influenced dyspnea severity. We hypothesized that if individuals with low income or difficulty accessing healthcare tend to minimize symptoms of dyspnea to delay seeking care, then they will report lower dyspnea severity under controlled conditions compared to other groups. The potential mechanism may underlie blunting the sensation of dyspnea due to the knowledge that they would not be able to seek care in an adequate time frame to cope with higher levels of dyspnea experienced in their daily lives. To test this hypothesis, we collected information regarding sociodemographic factors such as income, as well as healthcare access and attitudes, and determined if these factors were linked to self-reported dyspnea severity driven by experimentally induced changes in arterial oxygen and carbon dioxide.

METHODS

Ethical Approvals

This study was approved by the UC Riverside IRB (#22063). All participants were informed of the study risks and provided written informed consent prior to the experiment. The study was conducted in accordance with the Declaration of Helsinki, except for registration in a database.

Recruitment

Participants were recruited via word of mouth or flyers on campus. Prospective participants were sent a digital consent form to review ahead of the appointment. The consent forms were signed and sent back to the lab prior to scheduling a date for participants to partake in the study.

Inclusion criteria of individuals were between the ages of 18-65 who were fluent in English, had no history of cardiovascular or pulmonary disease, were not currently taking any anti-inflammatory medications, were not currently pregnant, had no recent travel above 8,000 feet elevation within one month of the experiment, and did not smoke. Participants refrained from consuming caffeine for at least 12 hours, did not take corticosteroids, aspirin, or other anti-inflammatory medications within 48 hours of their visit, and were asked to eat a small meal prior to the start of the study appointment (Mkrtchyan et al., 2024).

Basic Physiology Measures

We measured blood pressure using a manual physical or digital blood cuff (Model EBD-217, Elite Medical Instruments). Body temperature was gathered using an infrared thermometer on the forehead (Model DET-306, Femometer), and height and weight was recorded via self-reporting their measurements, or using an analog scale if they did not know their measurements. Oxygen saturation (SpO_2) was measured using a Nellcor N600x pulse oximeter (Medtronic, Minneapolis, MN, USA) with a finger probe. This pulse oximeter is validated to accurately measure SpO_2 above 68.5% as per Louie et al. (2017) and Severinghaus et al. (1987). A precision infrared carbon dioxide (CO_2) analyzer (Model 17630, Vacumed, Ventura, CA, USA) was used, drawing in air at 200 ml/minute to measure respired CO_2 partial pressures near the mouth. A paramagnetic oxygen analyzer (Model 17620, Vacumed, Ventura, CA, USA) was used to draw in air at a rate of 200 ml/min to measure oxygen (O_2) partial pressure. We recorded a diaphragmatic EMG (electromyography) using a Bioamp recorder by placing probes on the midclavicular line on the right side of the body on the seventh or eighth intercostal space to measure the electrical activity of muscle responses. We also measured a three-lead ECG (electrocardiography) using an ADInstruments (Colorado Springs CO, USA) Bioamp to measure the electrical activity of the heart. Inspired airflow rates were measured via placing a flow meter (Model MLT1000L, ADInstruments) directly upstream of the inhalation opening of the non-rebreathing valve. Subsamples of oxygen partial pressures (pO_2) and carbon dioxide partial pressures (pCO_2) were collected directly from the non-rebreathing valve position in front of the mouth (Mkrtchyan et al., 2024). All physiological data was collected from the same trained personnel to reduce variability of physiological data collection.

Questionnaire

A preliminary medical and physical questionnaire was provided at the start of the experiment to eliminate bias if conducted after the experiment and thereby reduce the chances of results being altered if the patient grew aware of the goal of the experiment. The survey asked questions regarding sociodemographic factors such as difficulty in accessing basic and emergency services, how inclined they were to report shortness of breath, how likely they were to seek care due to dyspnea if they knew it would require medical attention, and if patients felt positively or negatively about the care they were receiving. Participants were also asked how far their home was from the nearest local primary care physician to home, distance from the nearest hospital to home, whether they were working (and if they were working part-time or full-time) or in school, their highest rate of education, and whether a parent or guardian sought healthcare if a problem arose in the family. Demographic factors such as age, race, gender, income, country of birth, primary language spoken at home, and history of acute respiratory symptoms were asked in the survey before the experiment as well. Finally, participants were asked whether they or their family experienced certain sociodemographic challenges such as finding a place to live, getting enough food to eat, access to medicine, socializing, access to education, getting to work, participating in religious activities, socializing, keeping their job, and feeling safe in their relationship. The data from the pre-survey was gathered and examined in relation to data recorded from the experimentally induced dyspnea simulation. The questionnaire included 16 questions in total.

Dyspnea Simulation Experiments

Participants completed an experimental protocol in which the sensation of dyspnea was induced via exposure to hypercapnia and/or hypoxia. Participants had an oronasal face mask (7450 Series V2 Mask, Hands Rudolph, Cole Palmer, Shawnee, KS, USA) fitted over their nose and mouth and sat in a semi-recumbent position. The mask that was connected to a two-way non-rebreathing valve (Model 2600, Hans Rudolph). CO_2, O_2, SpO_2, EMG, ECG, and respiratory flow were measured via continuous-time signals, or analog signals, via an ADInstruments PowerLab 8/30 (Model ML870) rebreathing circuit. The output was delivered to a PC as a digital signal to record into LabChart8 pro software (AD Instruments). Participants self-reported dyspnea throughout the experiment in one of two ways: using a laser pointer where they were informed to measure their dyspnea on a large poster of a dyspnea scale of 1-10 placed in front of them on the wall after each 4-minute experimental or rest treatment period, or turning a knob that was connected to a linear potentiometer for participants to report their dyspnea throughout the experiment on a numerical rating scale of dyspnea. The scale was numbered between 1-10, to which they could visibly view the number they were reporting and the scale was recorded automatically into LabChart.

Dyspnea was stimulated by experimentally modifying arterial blood gas tensions of O_2 and CO_2. We used this technique as previous literature has shown a direct positive correlation between increased hypoxic and hypercapnic conditions and greater sensations of dyspnea (Kobayashi et al., 1996). This was accomplished using a gas mixer rotameter to alter inspired partial pressure of O_2, N_2, and CO_2 to (pO_2 and pCO_2, respectively) delivered through the rebreathing circuit and targeting 6 treatment conditions (**Table 1**). There was a separate treatment in which participants did not experience altered inspired partial pressures and instead breathed room air (treatment 0). Treatments were delivered over a 4-minute period at a random, participant-blinded order. 4-minute rest periods were given to the participant to inhale room air between each experimental period.

Table 1

Target Inspired pO_2 (mmHg) and Target Expired pCO_2 (mmHg) levels under each treatment condition

Treatment	Target Inspired pO_2 (mmHg)	Target Expired pCO_2 (mmHg)
0	room air	room air
1	149	45
2	149	52
3	80	45
4	80	52
5	68	45
6	68	52

Statistical Analysis

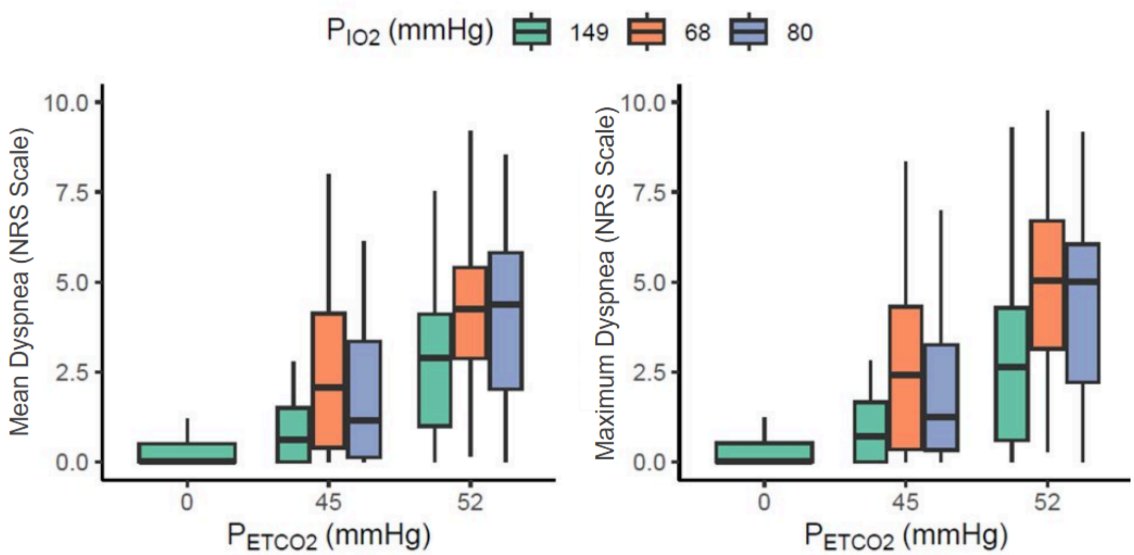
All statistical analyses were performed using R (version 4.3.3). The packages used were *ggplot2*, *ggprism*, *ggpubr*, *lme4* (Bates et al., 2015), *nlme* (Pinheiro & Bates, 2000), and *lmerTest* (Kuznetsova et al., 2017). To determine if each key questionnaire item contributed to dyspnea severity, general linear models were run with dyspnea as the outcome variable and demographic factors, age and sex as covariates. Experimental treatments were also included as covariates. Demographic items evaluated included: income, how challenging it would be to get the medicine they needed, their concern on the financial burden for seeking care, how likely their parents or guardians were to seek care, and difficulty in accessing healthcare. An ANCOVA was conducted to test the null hypothesis to investigate if there was no significant difference between each sociodemographic factor and self-reported dyspnea severity. Any factor with a main effect was further investigated using Spearman univariate correlations with dyspnea severity within treatments due to the non-normally distributed nature of the data.

RESULTS

Our study cohort included 44 participants with ages ranging from 18 and 49 years (22.86 ± 6.16 years old; 19 men and 25 women). As expected, our experimental treatment successfully induced the sensation of dyspnea. A repeated measures ANCOVA revealed a significant main effect of treatment on mean dyspnea ($F(6,582)=136.5$, $p<0.001$). Mean dyspnea scores, which were measured on a Numerical Rating Scale (NRS) of 0-10, increased from 0.55 ± 0.17 at baseline to 1.19 ± 0.23 at 45 mmHg end-tidal pCO_2 (the partial pressure of carbon dioxide that is measured at the end of an exhaled breath measured in millimeters of mercury, a unit of pressure), and 2.8 ± 0.23 at 52 mmHg end-tidal pCO_2. With a combined hypoxic stimulus, mean dyspnea scores increased further (**Figure 2**). Maximum dyspnea scores increased in association with end-tidal pCO_2 levels increasing during exposure to a combined hypoxic stimulus. Maximum dyspnea refers to the highest level of breathing discomfort reported by participants during the experiment under certain hypoxic or hypercapnic conditions. There was no significant difference in dyspnea scores based on if participants utilized the laser pointer or the continuous reporting via the voltmeter indicator (p=0.092).

Figure 2

Partial pressure of end-tidal pCO_2 as a function of mean dyspnea or maximum dyspnea.



Note. Results of Spearman univariate correlations between mean dyspnea or maximum dyspnea and the end-tidal pCO_2. Each model shows the score of self-reported mean (left) or maximum (right) dyspnea on a Numerical Rating Scale (NRS) in relation to the partial pressure of their end-tidal pCO_2. pIO_2 is the target inspired pO_2.

Tukey boxplots were visualized in each treatment as well, where the center line within the box indicates the median of the data. The box represents the interquartile range of the middle 50% of the data ranging between the 25th and 75th percentiles of scores. The whiskers connected to the outer points on each side of the box represent the outliers, and are calculated to be within 1.5 times the interquartile range from the quartiles of the box. The points exceeding beyond the whiskers represent the outliers of the data.

To determine if sociodemographic factors contributed to self-reported dyspnea, we conducted an ANCOVA to determine which question responses were associated with self-reported dyspnea within treatments. We found that the following question was the only one linked to dyspnea severity: "*When seeking emergency or basic health care, how difficult is it for you to access care? [1-10 scale]*" (**Table 2**). While participants had the opportunity to skip questions, all 44 responded to this question of the survey. While we obtained a significant number of responses for the other 15 questions; however, they did not significantly impact self-reported dyspnea severity.

Table 2

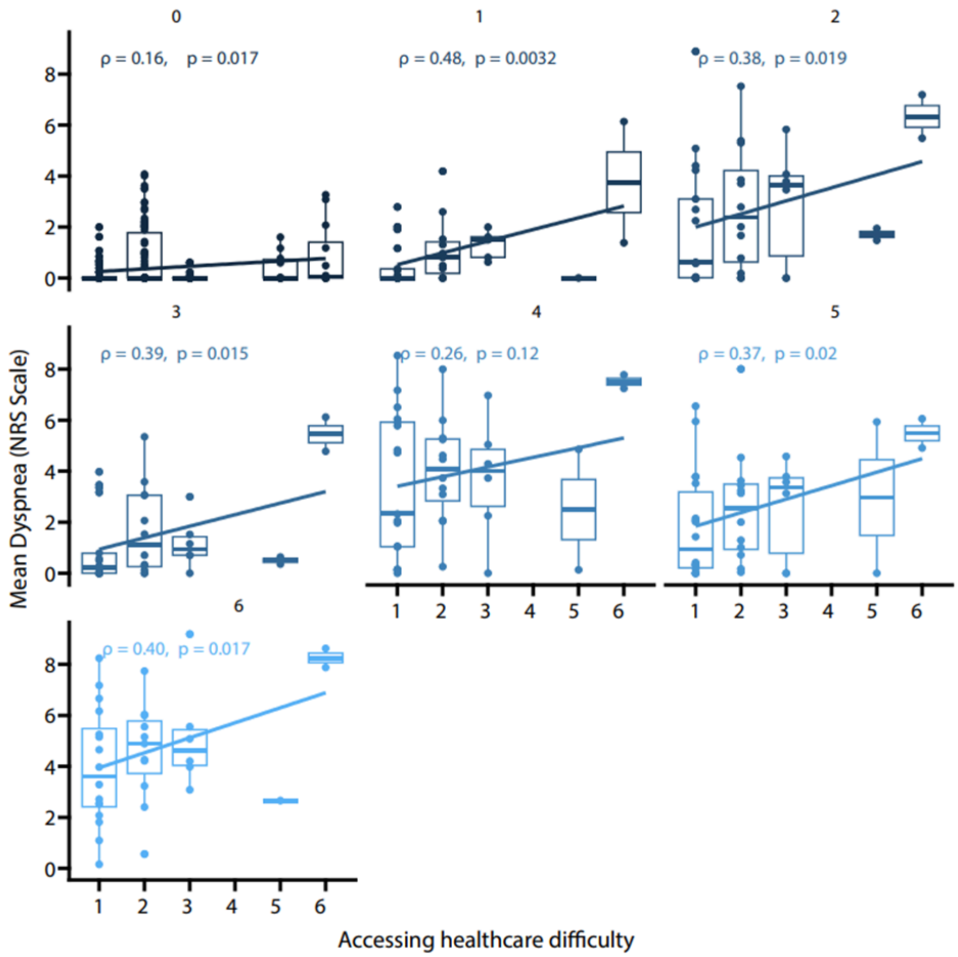
ANCOVA and Correlation Analysis Results for Accessing Healthcare Difficulty.

Treatment	**Target Inspired pO_2 (mmHg)**	**Target Expired pCO_2 (mmHg)**	**p-value**	**Correlation Coefficient**
0	room air	room air	$p = 0.017$	$R = 0.16$
1	149	45	$p = 0.0032$	$R = 0.48$
2	149	52	$p = 0.019$	$R = 0.38$
3	80	45	$p = 0.015$	$R = 0.39$
4	80	52	$p = 0.12$	$R = 0.26$
5	68	45	$p = 0.02$	$R = 0.37$
6	68	52	$p = 0.017$	$R = 0.40$

Note. ANCOVA main effect p-values, as well as Spearman univariate correlation Rho values, are provided demonstrating effects of healthcare access difficulty on dyspnea severity at room air (treatment 0) and under 6 experimentally induced treatments.

Figure 3

Mean Dyspnea as a function of Accessing Healthcare Difficulty, separated by treatment (treatment number listed above graph)



Note. Results of Spearman univariate correlations between healthcare access difficulty and dyspnea severity at room air (treatment 0) and under 6 experimentally induced treatments. Treatments are listed above each plot, numbered 0-6 as per Table 1. Each model shows the score of self-reported mean dyspnea on a Numerical Rating Scale (NRS) in relation to how difficult participants felt it was to access healthcare, measured on a scale of 1-10. A rating of 1 meant there was no difficulty finding and accessing healthcare and a rating of 10 indicated it was near impossible to access healthcare for the participant. Participant ID was not taken into account as all participants experienced the same treatments.

The data demonstrated a positive correlation between self-reported mean dyspnea and difficulty accessing healthcare. Specifically, as an individual's self-reported difficulty accessing healthcare increased, they tended to report higher feelings of dyspnea under all treatment conditions except for Treatment 4 (**Table 2**). There was no statistically significant effect in Treatment 4 between difficulty in accessing healthcare and mean dyspnea, which were mild hypoxic (80 mmHg) and intense hypercapnic (52 mmHg) conditions ($R=0.26$, $p=0.12$). Participants had the most significant correlation between dyspnea severity and difficulty accessing healthcare under treatment 1, which were low hypoxic (149 mmHg) and mild hypercapnic (45 mmHg) conditions, as the participant felt it more difficult to access healthcare ($R=0.48$, $p=0.0032$). There was no effect of any other sociodemographic variable on mean dyspnea severity explored in the study. There were no interactions between mean dyspnea as a function of any other sociodemographic variable explored in the study.

DISCUSSION

As expected, dyspnea severity increased under hypercapnic and hypoxic conditions. The correlation present between dyspnea and hypercapnic and hypoxic conditions has been established in previous studies (Kobayashi et al., 1996). In addition, our data show for the first time that increased limited access to medical services is correlated with elevated perceived dyspnea severity. This may be attributed to potential anxiety related to healthcare challenges.

The following mechanism (**Figure 4**) is proposed in replacement of **Figure 1** based on the newfound results.

Figure 4

Proposed mechanism for sociodemographic conditions affecting self-reported dyspnea severity based on results conducted in the experiment.

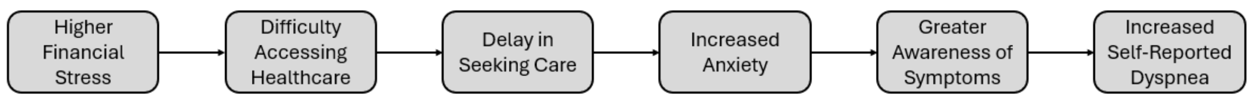


Figure 3 demonstrated a slight positive correlation between difficulty accessing healthcare and mean self-reported dyspnea. Despite the modest increase of self-reported dyspnea as healthcare becomes increasingly difficult to access, the heightened degree of perceiving dyspnea can significantly impact an individual in a clinical setting. Minimal changes can drive greater discomfort in dyspnea for individuals; if unaddressed, gaps in experiencing dyspnea can exacerbate pre-existing health disparities, as vulnerable populations are primarily affected by this increase in self-reported dyspnea. Recognizing these disparities in a clinical setting could drastically increase the accuracy in diagnosing individuals who experience this heightened perception of dyspnea.

Elevated levels of anxiety have been identified as a predictor of the perception of pain as well, as seen in (Keogh & Cochrane, 2002). The study investigated how sensitivity of experimental pain was correlated with amplified levels of anxiety, and found a positive correlation between the two variables. This altered cognitive perception could be attributed to a potential mechanism underlying hypervigilance of pain seen in individuals with impaired access to healthcare and their increased reporting of dyspnea. **Figure 4** proposes that, as barriers to adequate care exacerbate feelings of stress, anxiety can lead to individuals feeling their pre-existing symptoms of dyspnea are elevated, amplifying their tendency to report higher rates of perceived dyspnea. These feelings of anxiety may stem from a constant state of worry, as the belief that an individual experiences obstacles to accessing medical services that they may need could lead to uncertain outcomes of a pre-existing concern they may have when experiencing dyspnea.

A more neurobiological mechanism behind anxiety increasing pain sensitivity may be attributed to reduced neural gating of sensations, particularly of respiratory sensations in the context of this study. Chenivesse et al. (2014) demonstrated that negative stimulated situations could subject individuals to reduced sensory gating, or decrease the neural ability of filtering out stimuli that would otherwise be blunted to the consciousness of an individual. Further investigations correlated this inability to blunt stimuli with dyspnea, as demonstrated by Herzog et al. (2018). Specifically, reduced neural gating, or filtering repetitive sensory inputs before reaching higher-level cortical processes to exclude them as a conscious sensation, of respiratory sensations was correlated with the increased perception of dyspnea (Herzog et al., 2018). Anxiety, which has coincided previously with elevated perceptions of dyspnea, was associated with reduced neural gating in the brain and could thus suggest that this blunted ability to filter out repetitive stimuli could be the neurobiological mechanism for heightened sensitivity of pain in individuals, further exacerbated in dyspnea.

Mkrtchyan et al. in preparation has investigated those who face difficulty in accessing healthcare may be associated with higher baseline levels of anxiety. Preliminary data suggests that baseline levels of anxiety (Trait Anxiety) and levels of anxiety when given a negative stimulus (State Anxiety) correlates with increased self-reported mean dyspnea, further amplified when difficulty accessing healthcare functions as a covariate. These findings may further support the mechanism linking restricted healthcare access with the increased perceived severity of dyspnea, as seen in **Figure 4**.

Figure 3 demonstrated the positive correlation between difficulty accessing healthcare and mean self-reported dyspnea as a marginal upward trend. Despite the modest increase in the correlation, the heightened degree of perceiving dyspnea can significantly impact an individual in a clinical setting as minimal changes can drive greater discomfort in dyspnea for individuals. If unaddressed, gaps in experiencing dyspnea can exacerbate pre-existing health disparities, as vulnerable populations are primarily affected by this increase in self-reported dyspnea. Recognizing these disparities in a clinical setting could drastically alter the diagnosis of individuals experiencing this heightened perception of dyspnea.

Experiencing greater dyspnea severity when struggling to access healthcare can be attributed to clinical perceptions of dyspnea as well. Sunjaya et al. (2022) conducted a literature review revealing little research has been conducted to guide clinicians in accurately diagnosing dyspnea. Common methods diagnosing dyspnea are prevalent, such as extensive physical examinations including spirometry, full blood count, electrocardiogram, and chest X-ray. However, these methods are time-consuming, difficult, and costly to patients, which may deter patients from further investigation of conditions. Misdiagnose is also possible in patients who are experiencing greater feelings of breathing discomfort by attributing the symptom to pre-existing conditions. Utilization of findings concluded in this study can be applied by clinicians to patients who may experience healthcare barriers and emphasize investigation of conditions underlying heightened awareness of dyspnea.

Understanding sociodemographic effects on dyspnea is important to elevate the quality of life to those impeded by breathing discomfort. As Zajacova et al. (2021) demonstrated an inverse relationship between pain trends and socioeconomic status, pain inhibits the subjective well-being of an individual in lower socioeconomic standing to a greater extent than other groups. Consequently, sociodemographic factors such as household income are correlated with an increase in self-reported pain perception. These socioeconomic conditions are also linked to disparities in accessing care in a timely fashion according to the National Healthcare Quality and Disparities Report. Lower socioeconomic conditions include navigating to local clinics, financial means and affordability for care, and distance from individuals to near basic and emergency medical services. Therefore, there exists a strong association between difficulty in accessing healthcare and increased perception of pain as lower socioeconomic status bridges the two conditions, as seen in **Figure 4**. Although sociodemographic experiences such as income and distance to care were not found to be statistically significant in this study, they can contribute to limiting medical access which is linked to higher reports of dyspnea severity**.** Gaffney et al. (2021) also demonstrated how socioeconomic inequalities in lung health and dyspnea experience has remained prevalent, if not worsened since 1959. Income-based gaps were primary drivers of disparity, despite overall improvements in healthcare as of recent years. Lower socioeconomic conditions have thus been linked to increased pain perception in patients, which may be attributed to delayed diagnosis and treatment, can worsen the emotional or mental toll on patients, and further increase the disparity amongst socioeconomic groups in medical services.

Lastly, pain such as back pain, chest pain, and arthritis pain has previously been linked with dyspnea as per Clark et al. (2014). Participants included Medicare Managed Care patients, who are mandated to be below an income threshold to be eligible for healthcare, emphasizing the study’s focus on lower economic standing and the participants linking greater awareness of pain and dyspnea together. Thus, the link between other forms of pain and self-reported dyspnea, coincided with lower socioeconomic status being strongly associated with increased difficulty accessing healthcare, can serve as a potential mechanism to elevated awareness of dyspnea (Figure 2). This could be driven by anxiety if one recognizes they are unable to reach proper healthcare in time to investigate their acute dyspneic symptoms (**Figure 4**).

This research contributes to understanding patient perception of bodily sensations in correlation with sociodemographic factors, and how barriers to providing medical services contributes significantly to a worsened experience in dyspnea severity. This would also allow for physicians to investigate dyspnea symptoms as a relation to healthcare access. As gaps in healthcare access contribute to greater dyspnea severity, research may be progressed and policies implemented to aid and educate patients on healthcare opportunities, lessening the gap on disparate healthcare access. Providing educational opportunities and pushing for the establishment of clinics in areas historically lacking in healthcare opportunities may lessen the burden on individuals experiencing such dyspnea severity. Institutions and organizations could also focus resources on building more clinical resources in underserved areas, an essential factor increasing the quality of life for individuals as less healthcare access is linked to worsened dyspnea experience in individuals. The accumulation of participant perception and understanding of healthcare, clinician investigation of dyspnea, and governmental implementation of healthcare resources and educational opportunities can lessen the overall disparity seen amongst groups and decrease hurdles for medicine when experiencing dyspnea. Guiding policies to focus on bridging healthcare access in what research finds could close the gap not only in providing equitable medical services, but also in lessening the burden of dyspnea to those who suffer from said barriers and increase the quality of life for many underserved populations.

FUTURE RESEARCH DIRECTIONS

Sociodemographic variables are complex and contain many confounding variables that contribute to certain correlations. Future studies can investigate mechanisms that potentially contribute to certain sociodemographic variables, particularly on how access to healthcare may amplify dyspnea severity to patients. Research furthering investigation in potential barriers to healthcare access and its contribution to dyspnea severity may also narrow the potential factors of why this correlation occurs.

LIMITATIONS

The experiment included limitations. The survey included a question asking what the participant could best estimate their total annual income was from all sources before taxes within a year. This included money from jobs, social security, retirement income, unemployment payments, public assistance, and any other money income such as gifts. Many participants in the demographic included students who reported their own income and did not include family income that they may depend on. This could have distorted results between income and mean dyspnea, and their relationship with other covariates, as the income could have been reported to be lower than the income many students had access to, leading all data on income to be statistically insignificant. The demographic was limited as well, as not many participants reported higher income, as few participants reported an annual income higher than $40,000-$50,001. It was thus difficult to gather information and compare drastic socioeconomic differences in terms of annual income. Participants also reported low or mild difficulty in accessing healthcare, so results could not be pertained to individuals who may experience intense difficulty in accessing healthcare.

CONCLUSION

Our data indicates that healthcare access and anxiety level may influence the perception of dyspnea symptoms. This may impact clinical outcomes of disease, potentially facing symptoms to a more severe degree due to the delay in seeking healthcare until necessary. We show that individual variation in dyspnea severity is partially driven by preventable sociodemographic factors including equitable medical access. The mechanism underlying this link warrants further investigation.

REFERENCES

ACCESS TO HEALTHCARE AND DISPARITIES IN ACCESS. (2021). In *2021 National Healthcare Quality and Disparities Report [Internet]*. Agency for Healthcare Research and Quality (US). https://www.ncbi.nlm.nih.gov/books/NBK578537/

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using **lme4**. *Journal of Statistical Software*, *67*(1). https://doi.org/10.18637/jss.v067.i01

Chenivesse, C., Chan, P.-Y., Tsai, H.-W., Wheeler-Hegland, K., Silverman, E., von Leupoldt, A., Similowski, T., & Davenport, P. (2014). Negative emotional stimulation decreases respiratory sensory gating in healthy humans. *Respiratory Physiology & Neurobiology*, *204*, 50–57. https://doi.org/10.1016/j.resp.2014.08.019

Clark, N., Fan, V. S., Slatore, C. G., Locke, E., Whitson, H. E., Nici, L., & Thielke, S. M. (2014). Dyspnea and Pain Frequently Co-occur among Medicare Managed Care Recipients. *Annals of the American Thoracic Society*, *11*(6), 890–897. https://doi.org/10.1513/AnnalsATS.201310-369OC

Currow, D. C., Plummer, J. L., Crockett, A., & Abernethy, A. P. (2009). A Community Population Survey of Prevalence and Severity of Dyspnea in Adults. *Journal of Pain and Symptom Management*, *38*(4), 533–545. https://doi.org/10.1016/j.jpainsymman.2009.01.006

Edwards, R. R., Doleys, D. M., Fillingim, R. B., & Lowery, D. (2001). Ethnic differences in pain tolerance: Clinical implications in a chronic pain population. *Psychosomatic Medicine*, *63*(2), 316–323. https://doi.org/10.1097/00006842-200103000-00018

Gaffney, A. W., Himmelstein, D. U., Christiani, D. C., & Woolhandler, S. (2021). Socioeconomic Inequality in Respiratory Health in the US From 1959 to 2018. *JAMA Internal Medicine*, *181*(7), 968–976. https://doi.org/10.1001/jamainternmed.2021.2441

Herzog, M., Sucec, J., Diest, I. V., Bergh, O. V. den, Chan, P.-Y. S., Davenport, P., & Leupoldt, A. von. (2018a). Reduced neural gating of respiratory sensations is associated with increased dyspnoea perception. *European Respiratory Journal*, *52*(1). https://doi.org/10.1183/13993003.00559-2018

Herzog, M., Sucec, J., Diest, I. V., Bergh, O. V. den, Chan, P.-Y. S., Davenport, P., & Leupoldt, A. von. (2018b). Reduced neural gating of respiratory sensations is associated with increased dyspnoea perception. *European Respiratory Journal*, *52*(1). https://doi.org/10.1183/13993003.00559-2018

Hoseini-Esfidarjani, S.-S., Negarandeh, R., Delavar, F., & Janani, L. (2021). Psychometric evaluation of the perceived access to health care questionnaire. *BMC Health Services Research*, *21*(1), 638. https://doi.org/10.1186/s12913-021-06655-2

Ikram, A. S., & Pillay, S. (2022). Admission vital signs as predictors of COVID-19 mortality: A retrospective cross-sectional study. *BMC Emergency Medicine*, *22*, 68. https://doi.org/10.1186/s12873-022-00631-7

Keogh, E., & Cochrane, M. (2002). Anxiety sensitivity, cognitive biases, and the experience of pain. *The Journal of Pain*, *3*(4), 320–329. https://doi.org/10.1054/jpai.2002.125182

Kobayashi, S., Nishimura, M., Yamomoto, M., Akiyama, Y., Miyamoto, K., & Kawamaki, Y. (1996). Relationship between breathlessness and hypoxic and hypercapnic ventilatory response in patients with COPD. *The European Respiratory Journal*, *9*(11), 2340–2345. https://doi.org/10.1183/09031936.96.09112340

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). **lmerTest** Package: Tests in Linear Mixed Effects Models. *Journal of Statistical Software*, *82*(13). https://doi.org/10.18637/jss.v082.i13

Louie, A., Feiner, J. R., Bickler, P. E., Rhodes, L., Bernstein, M., & Lucero, J. (2018). Four Types of Pulse Oximeters Accurately Detect Hypoxia during Low Perfusion and Motion. *Anesthesiology*, *128*(3), 520–530. https://doi.org/10.1097/ALN.0000000000002002

Michaelides, A., & Zis, P. (2019). Depression, anxiety and acute pain: Links and management challenges. *Postgraduate Medicine*, *131*(7), 438–444. https://doi.org/10.1080/00325481.2019.1663705

Mixed-Effects Models in S and S-PLUS. (2000). Springer-Verlag. https://doi.org/10.1007/b98882

Mkrtchyan, K., Lohn, B., Qazi, A., Ma, S., & Heinrich, E. (2024). Addressing Disparities Between Physician Rated and Self-Reported Dyspnea Using Machine Learning. *Physiology*, *39*(S1), 2192. https://doi.org/10.1152/physiol.2024.39.S1.2192

Pinheiro, J., & Bates, D. (2000). *Mixed-Effects Models in S and S-PLUS*. Springer-Verlag. https://doi.org/10.1007/b98882

Severinghaus, J. W., & Naifeh, K. H. (1987). Accuracy of response of six pulse oximeters to profound hypoxia. *Anesthesiology*, *67*(4), 551–558. https://doi.org/10.1097/00000542-198710000-00017

Stephenson, J. J., Wertz ,Debra, Gu ,Tao, Patel ,Jeetvan, & and Dalal, A. A. (2017). Clinical and economic burden of dyspnea and other COPD symptoms in a managed care setting. *International Journal of Chronic Obstructive Pulmonary Disease*, *12*, 1947–1959. https://doi.org/10.2147/COPD.S134618

Sunjaya, A. P., Homaira, N., Corcoran, K., Martin, A., Berend, N., & Jenkins, C. (2022). Assessment and diagnosis of chronic dyspnoea: A literature review. *Npj Primary Care Respiratory Medicine*, *32*(1), 10. https://doi.org/10.1038/s41533-022-00271-1

Zajacova, A., Grol-Prokopczyk, H., & Zimmer, Z. (2021). Pain Trends Among American Adults, 2002–2018: Patterns, Disparities, and Correlates. *Demography*, *58*(2), 711–738. https://doi.org/10.1215/00703370-8977691