Predicting Factors Influencing Systolic Blood Pressure: A Retrospective Analysis of the UCLA Nurse Blood Pressure Study

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Abstract

The primary research question of this study is to determine which factors are associated with higher systolic blood pressure (BP) among a sample of registered nurses in the UCLA Nurse Blood Pressure Study. A total of 203 subjects between the ages of 24 and 50 were included in this analysis. Systolic BP measurements were recorded approximately every 20 minutes, accompanied by the nurses' self-assessments of emotional states and physical activity levels using an actigraph. This report investigates how familial history of hypertension, mood fluctuations, occupational status, and physiological states such as menstrual phases correlate with systolic BP readings. The objective is to identify significant predictors of elevated systolic BP, a crucial cardiovascular risk factor. Hypertension affects 1 in 4 Canadians and is implicated in 12.8% of global deaths. Understanding the risk factors for developing high systolic BP among nurses is critical to the overall health and well-being of this workforce.

Introduction

Hypertension remains a critical issue in global health challenges, with elevated systolic blood pressure (BP) as a significant risk factor for cardiovascular morbidity and mortality. Systolic BP captures the maximum arterial pressure during heart contraction and possibly predicts cardiovascular events more accurately than diastolic BP. While a healthy adult's average systolic BP is ~120 mmHg, the measurements are significantly influenced by several physiological, genetic, mental, and behavioural factors.

The UCLA Nurse Blood Pressure Study focuses on a sample of 203 registered nurses between the ages of 24 and 50 to dissect the complex interplay of factors influencing systolic blood pressure. The dataset contains demographic, physiological, and self-reported psychological variables collected from registered nurses. In the dataset, age was measured in years; working status was recorded as either 'Workday' (W) or 'Non-workday' (NW); diastolic BP (DIA) was recorded in millimetres of mercury (mmHg), alongside the measure of interest, systolic BP (SYS). Family history of hypertension (FH123) was categorized by parental hypertension, delineated as 'NO' for no history, 'YES' for one hypertensive parent, and 'YESYES' if both parents are hypertensive. Subjective measures of well-being are quantified through a 5-point scale for happiness (HAP), stress (STR), and tiredness (TIR), with higher scores indicating stronger feelings. Heart rate (HRT) is captured in beats per minute, and activity level (MNACT5) is quantified as the frequency of movement in one-minute intervals over ten minutes. The menstrual phase (PHASE) is noted as either follicular (F) or luteal (L), and posture (POSTURE) is observed at the time of blood pressure measurement. Subject identifiers (SNUM) ensure discrete subject data, while the 'time' variable indicates minutes since midnight, 'timepass' records the interval between consecutive measurements starting from zero at the first point, and 'timept' tracks the approximate 50 measurement occasions for each subject. This dataset, with its various predictors, provides a foundation for analyzing the multifactorial influences on blood pressure among nurses.

We developed a conceptual model using a literature review to guide our statistical analysis and determine variables that may be predictive of systolic BP. Next, we employed an exploratory data analysis to observe patterns present in the data and to observe possible covariates for modelling. Using the information gathered from the conceptual model and the exploratory analysis, a linear mixed effects model was fit. Linear mixed effects models allow for an examination of fixed and random effects and provides a comprehensive understanding of how variables affect systolic BP. Here, we discuss the results of our analysis including the methodologies employed, model construction, the results of our model, and a discussion of the implications on nursing practices and health policy.

Methods

Data Source and Description

The data were provided as part of the course requirements for CHL5222H: Analysis of Correlated Data at the Dalla Lana School of Public Health, University of Toronto. The data were obtained from the University of California, Los Angeles (UCLA) Nurse Blood Pressure Study, which collected information from registered nurses in the Los Angeles area. The study aimed to determine physical and psychological characteristics that may be predictive of BP among nurses aged 24 to 50. Some factors included in the dataset are family history, personality, mood changes, activity level, and working status; a full list of the variables included in the dataset can be seen in Table 1.

The primary outcome we were interested in predicting was systolic BP measured in millimetres of mercury (mmHg). An initial BP reading was taken 30 minutes before the start of the nurse's shift, and BP readings were taken every 20 minutes thereafter for the remainder of the workday. Subjects rated their mood and activity level at the time of each BP reading.

Building a Conceptual Model: Directed Acyclic Graph

A conceptual model was constructed to guide our analysis (Figure 1). Literature reviews were completed to determine the variables included in our dataset that may be predictive of a subject's systolic BP; if a variable had a theoretical basis for modifying a subject's BP, it was included in the model. Moreover, some variables were noted to potentially modify the relationship between other exposures and the outcome, and these were included as interactions in the conceptual model.

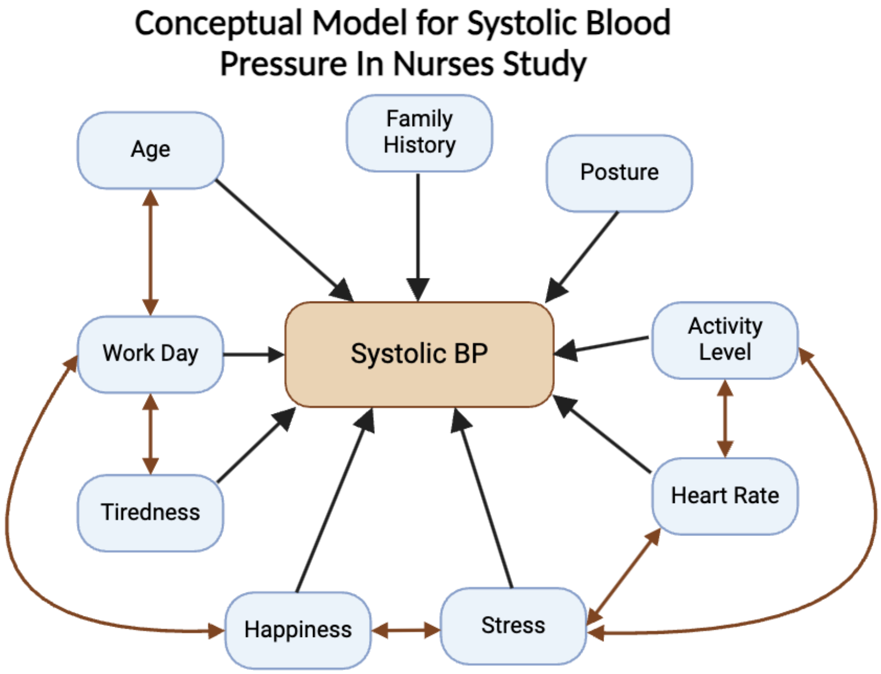

Figure 1. Conceptual diagram for variables in the UCLA Nurses Blood Pressure Study. The outcome we are interested in predicting is shown at the centre in brown, and the variables included in the dataset are shown in blue. Interactions between variables in the dataset are shown as double-headed brown arrows.

Exploratory Data Analysis

All variables included in the conceptual model were subject to exploratory data analysis. Summary statistics were calculated for each exposure variable, including mean and standard deviation for continuous variables and percent of responses in each category for categorical variables. Plots were constructed to observe the response distribution with respect to the outcome variable (systolic BP). Variables that had a sufficient distribution of responses across the scale of BP measurements were considered for inclusion in the final model. Interactions among responses were also considered. The number of measurements for each nurse in the study was observed to determine the proportion of missing data, and the pattern of drop-out was observed.

Statistical Analysis: Model Construction

A linear mixed-effects model was fit to the data with systolic BP (mmHg) as the response and random intercepts for each subject. Main effects for exposure variables included in the model were stress level, family history of hypertension, workday, age, tiredness, heart rate, and activity level. Additionally, interaction terms were added for workday and age, and heart rate and activity level.

Results

A total of 9,573 observations on 203 individuals were included in this study, and their baseline characteristics are described (Table 1). The subjects' mean age across the observations was 37.8 years, a mean heart rate of 80 bpm, and the average systolic BP measured was 118 mmHg. The continuous predictors were generally normally distributed, except for a slight left-skewness for the activity level predictor. Notably, there were few observations for the highest level of self-rating for stress (n=56). Based on this analysis, the variables appear to have sufficient response distribution for modelling. The complete case analysis included a total of 7,877 observations.

Table 1. Descriptive statistics of baseline characteristics from registered nurses in the Los Angeles area between 24 and 50 years of age on BP and potential factors that contribute to hypertension (n=9,573).

Characteristic			
Systolic BP, mmHg		**Position during BP measurement**	
Mean (SD)	118 (15.5)	Standing	4,255 (44.4%)
Median [Min, Max]	117 [75.0, 200]	Sitting	4,101 (42.8%)
Age, years		Reclined	631 (6.6%)
Mean (SD)	37.8 (6.63)	Missing	586 (6.1%)
Median [Min, Max]	38.0 [24.0, 50.0]	**Self-rating for level of stress**	
Heart rate, beats per minute		1 (Low)	5,599 (58.5%)
Mean (SD)	80.0 (13.2)	2	2,243 (23.4%)
Median [Min, Max]	80.0 [35.0, 144]	3	737 (7.7%)
Activity level, frequency of movement		4	184 (1.9%)
Mean (SD)	190 (65.5)	5 (High)	56 (0.6%)
Median [Min, Max]	207 [0, 359]	Missing	754 (7.9%)
Missing	985 (10.3%)	**Self-rating for level of happiness**	
Menstrual phase		1 (Low)	920 (9.6%)
Follicular	4,737 (49.5%)	2	1,579 (16.5%)
Luteal	4,836 (50.5%)	3	3,132 (32.7%)
Workday		4	2,082 (21.7%)
Yes	5,457 (57.0%)	5 (High)	1,105 (11.5%)
No	4,116 (43.0%)	Missing	755 (7.9%)
Family history of hypertension		**Self-rating for level of tiredness**	
No family history	5,298 (55.3%)	1 (Low)	3,918 (40.9%)
1 hypertensive parent	3,633 (38.0%)	2	2,458 (25.7%)
Both parents hypertensive	642 (6.7%)	3	1,585 (16.6%)
		4	640 (6.7%)
		5 (High)	217 (2.3%)
		Missing	755 (7.9%)

Table 2. Parameter beta estimates, standard errors (SE), and 95% confidence intervals (CI) for the linear mixed effects model results with random subject-level intercepts for potential factors influencing systolic BP (mmHg) following complete case analysis (n=7,877).

Characteristic	**Beta**	**SE**	**95% CI**	**p-value**
Intercept	82.96	6.17	70.87, 82.96	**<0.001**
Age, years	0.29	0.14	0.01, 0.57	**0.042**
Heart rate, beats per minute	0.20	0.04	0.12, 0.27	**<0.001**
Activity level, frequency of movement	0.07	0.01	0.04, 0.10	**<0.001**
Workday				
No (ref)	—		—	
Yes	16.78	7.02	2.92, 30.65	**0.018**
Family history of hypertension				
No family history (ref)	—		—	
1 hypertensive parent	-0.28	1.26	-2.76, 2.20	0.8
Both parents hypertensive	6.57	2.37	1.89, 11.25	**0.006**
Self-rating for level of stress				
1 (ref)	—		—	
2	0.70	0.39	-0.06, 1.46	0.069
3	0.15	0.61	-1.05, 1.34	0.8
4	2.30	1.04	0.27, 4.34	**0.026**
5	3.30	1.82	-0.27, 6.86	0.070
Self-rating for level of tiredness				
1 (ref)	—		—	
2	-0.22	0.42	-1.05, 0.60	0.6
3	-0.73	0.49	-1.69, 0.23	0.13
4	-1.86	0.65	-3.14, -0.59	**0.004**
5	-1.05	1.06	-3.12, 1.02	0.3
Age × Workday	-0.38	0.18	-0.74, -0.02	**0.041**
Heart rate × Activity level	0.00	0.00	0.00, 0.00	**0.022**
Subject-level SD (Intercept)	7.67			
Residual SD (Observations)	12.54			

Figure 2 shows the observed values with respect to the continuous predictors (age, heart rate, and activity level) and the response variable, systolic BP. All three continuous covariates were statistically significant ($p<0.05$) and positively correlated. On average, systolic BP is expected to increase by 2.9 mmHg per decade, 2.0 mmHg per 10 bpm increase in heart rate, and 0.07 bpm per unit increase in activity level measured (Table 2). For the categorical covariates, specific factors were identified as statistically significant predictors. Systolic BP is expected to be 16.9 mmHg higher on workdays than non-workdays, 6.6 mmHg higher if both parents were hypertensive relative to those with no family history of hypertension, 2.3 mmHg higher if the self-reported stress level was 4 compared to the lowest level, and 1.9 mmHg lower if the self-reported tiredness level was 3 compared to the lowest level (Table 2). In addition, both interaction effects included in the model were statistically significant. The relationship of age with systolic BP is modified by working status, as the systolic BP is expected to decrease by 3.8 mmHg per decade if the measurements are taken when the subject is working than not working (Table 2). The relationship of heart rate with systolic BP is also modified by activity level (Table 2).

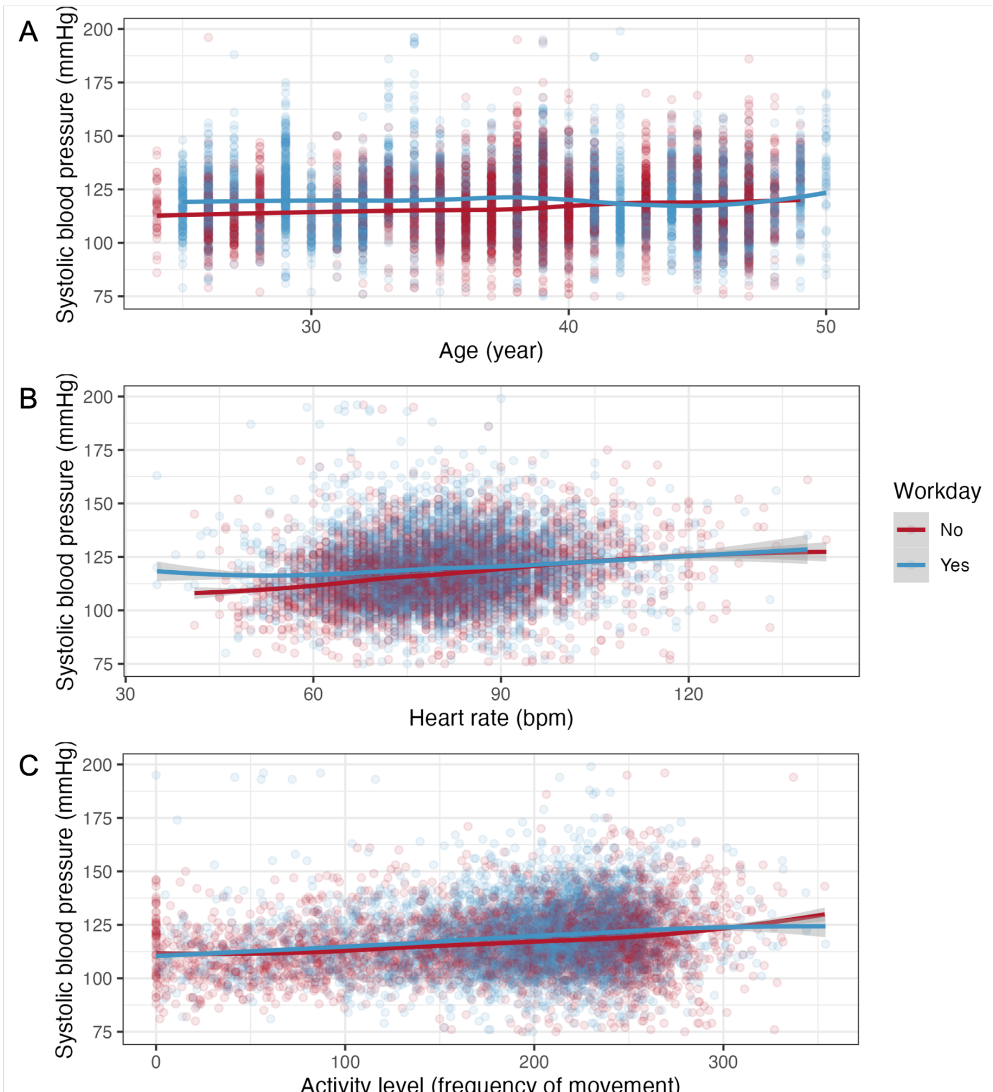

Figure 2. Scatterplots of observed values and predictive margins derived from the linear mixed effects model of the systolic BP, stratified by workday status, and with respect to the continuous covariates (A) age, (B) heart rate, and (C) activity level. The margins shown are smoothed conditional means of the marginal values by local polynomial regression fitting.

Discussion

This study aimed to investigate and identify factors influencing systolic BP among registered nurses. The nursing profession's high-demand environment uniquely positions it for studying the variations in systolic BP. Nurses are regularly exposed to factors that may elevate systolic BP, such as prolonged work-related stress, irregular shifts that disrupt circadian rhythms, and the physical exertion required by their roles. Addressing these specific factors is crucial for preventing the negative health outcomes that may hinder their capacity for providing high-quality patient care. To examine these factors, this study employed a linear mixed effects model fitted to the UCLA Nurse Blood Pressure Study data, which provided significant insights into the complex interplay between these factors and systolic BP.

The analysis identified age as a significant predictor of systolic BP. Previously, the Framingham Heart Study[1] and the third National Health & Nutrition Examination Survey (NHANES III)[2] demonstrated a high prevalence of elevated systolic BP in older populations versus younger populations. Aging-associated physiological changes, such as narrowing of arterial lumen and narrowing of arterial walls, are likely responsible for the increase in systolic BP seen with age.[3] The interaction between age and workday was also significant, implying that the effect of age depends on whether the nurse had a working day or non-working day. Figure 1A depicts the impact of age on systolic BP stratified by workday status. On non-workdays, systolic BP demonstrates a positive correlation with age, as expected. However, on workdays, systolic BP tends to be higher among nurses under 40 years of age compared to their older counterparts. While this observation contrasts with the expectation that blood pressure increases with age, one plausible explanation is that younger nurses may encounter more stressful and demanding work assignments relative to their older colleagues. Additionally, the novelty and unfamiliarity of the job may contribute to heightened stress levels among younger nurses, whereas older nurses, being more experienced, may be better at managing job-related stressors.

Furthermore, our results showed heart rate to have a positive association with systolic BP. The relationship between heart rate and systolic BP, potentially due to increased sympathetic nervous system activity or heightened physical exertion, is corroborated by existing literature. These results align with previous studies, such as the Italian TensoPulse Study and the HARVEST study, which identified heart rate as a predictor of hypertension.[4,5] Our model also identified activity level as a significant predictor of systolic BP, with higher activity levels associated with higher systolic BP. A particularly noteworthy relationship is the influence of workday on systolic BP, with nurses experiencing a significant increase of 16.8 mmHg in systolic BP on workdays compared to non-workdays. This result is especially significant as previous work has frequently failed to show an association between job strain and blood pressure in women.[6–8] Therefore, our results emphasize the impact of occupational stress on blood pressure in a demanding profession such as nursing and highlight the importance of addressing this as a risk factor in healthcare professionals.

The impact of psychosocial factors, such as tiredness and stress levels, were also investigated in this study. Stress is a well-known risk factor for hypertension, and our findings confirm this.[9,10] A significant difference in systolic BP between heightened stress levels was identified. Conversely, systolic BP was negatively correlated with tiredness. However, significant differences between the lowest and highest levels were not identified for either of the psychological factors. This may be due to the smaller sample size of individuals identifying with the highest level of stress or tiredness, as Table 1 shows that only 0.6% of individuals responded with stress level 5, and only 2.3% responded with tiredness level 5. The final significant predictor identified in our analysis was a family history of hypertension. Interestingly, only individuals with a history of hypertension in both parents demonstrated a significant association with elevated systolic BP. This observation aligns with previous literature emphasising the importance of family history as a non-modifiable risk factor for hypertension, further reinforcing its significance in understanding and predicting blood pressure-related outcomes.[11,12]

The findings of this study have important implications for nursing practice and policy. Given the high prevalence of hypertension among nurses and its potential impact on patient care outcomes, the identification of specific risk factors provides insight for tailored interventions aimed at high-risk individuals. However, as the study sample comprised registered nurses from a specific geographic area, generalizability of the findings to other populations may be limited. Furthermore, the lack of inclusion of typical factors known to impact blood pressure, such as BMI, smoking status and medication use, is another limitation. These factors could be confounding variables whose impact is unmeasured in the study.

Notwithstanding these limitations, the present study identified age, heart rate, activity level, working status, tiredness, stress and family history as significant predictors of systolic BP among active registered nurses. This research advances our understanding of the complex determinants of systolic BP. By identifying modifiable risk factors and informing targeted interventions, we can work towards improving the well-being of nurses and enhancing the quality of patient care delivery.

Data Availability

The relevant code and data used to perform this analysis can be found on the following GitHub repository: https://github.com/Keenancelliott/CHL5222H_AnalysisOfCorrelatedData.

Author Contributions

All authors contributed equally to this manuscript.

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