Electronic Health Records - The New Future of Healthcare?

Personal health record usage is associated with better diabetic outcomes, especially in younger users.

Abstract:

Electronic health resources are playing an increasingly important role in health care. However, the generational gap in technology usage presents a barrier for older populations to access online health records, which could affect their health outcomes. Using data on electronic personal health record (PHR) usage from the Cleveland Health Clinic, we fit a linear regression model with interactions to assess whether there is an association between PHR usage and diabetic outcome (quantified by HbA1c%), and whether this relationship depended on the user's age. While controlling for confounding variables such as race, gender, sex, income, and BMI, PHR users had lower expected HbA1c% than nonusers, and the magnitude of the expected difference in HbA1c% depended on the user's age. Results such as these indicate the importance of expanding access to populations who currently struggle to use technology to ensure the best health outcomes for all.

Introduction:

The advent of widespread internet usage has spawned new healthcare practices as health information can now be distributed and personal information collected online. Electronic health records are an important aspect of electronic health resources as they improve the organization and continuity for a patient's health team, improving the quality of care the patient receives (HealthIT.gov, n.d.), and previous research has demonstrated that the use of internet resources can indeed improve health outcomes (Jiang & Street, 2017).

However, the generational based technological usage gap is a barrier to ubiquitous access to internet resources. Despite technology usage rising in older populations, their internet usage for health-related purposes is still not comparable to that of younger age groups (Papp-Zipernovsky et al., 2021). As utilization of internet resources for health is a powerful tool for positive health outcomes and older populations generally suffer from poorer health, it is important to understand how age is related to the use of and benefit from online health services. This knowledge can serve as a starting point for clinicians, personal health record (PHR) designers, and public health officials to assess whether resources are serving all generations well and if not, adjust accordingly. Thus, we examine whether there is an association between PHR usage and diabetic outcomes, and if so, whether it depends on the user's age.

To address this question, we used data on patient usage of electronic PHRs from the Cleveland Clinic's departments of internal and family medicine (Tenforde et al., 2012). The Cleveland Clinic made electronic PHRs available for free to all patients in 2008 and as of July 2010, 20-40% of patients used the system. Patients need the internet to access their PHR, which includes information on their diagnoses, test results, comorbidities, and secure messaging with their provider. Data on PHR usage, health status, and demographics was collected from patients aged 19-77 years with actively managed diabetes between July 2008 and June 2009. Our analysis used HbA1C%, or hemoglobin bound to glucose, as our health outcome of interest as it is directly related to blood glucose levels (Health Direct, 2021).

Given our background research, we hypothesize that there is a negative association between PHR usage and HbA1c%. Furthermore, given the generational gap in technology usage and competency (Papp-Zipernovsky et al., 2021), we hypothesize that this association depends on the user's age.

Methodology:

While the original dataset contained medical records from 10,746 patients (Tenforde et al., 2012), we limited our analysis to only include complete cases for model predictors, reducing the dataset to 9,977 patients. To understand the main predictor and outcome variables in our dataset, we plot the relationship between age and HbA1c% levels, stratified by usage status of the PHR system (**Appendix Figure A1**). The distribution for age suggests a left-skewed distribution consisting mostly of older patients, and the distribution of HbA1c% indicates that the majority of patients are classified as diabetic (6.5% or higher) ("Glycosylated Haemoglobin & Diabetes," 2019). We see that PHR usage status was highest among younger ages with lower HbA1c% levels.

To test our hypotheses, we fit a multiple linear regression model with interactions. In our model, the outcome variable was HbA1c %, and our predictors were the continuous variables BMI, age, and income, and the categorical variables PHR user status, sex, and race. Additionally, we included an interaction term between PHR user status and age. We selected the variables for our models due to prior background research; income (Berkowitz et al., 2014), sex (Faerch et al., 2010), BMI (Sepp et al., 2014), and race (Do Glycemic Marker Levels Vary by Race, n.d.) were included because previous work has shown that they correlate with blood sugar levels. Thus, we wanted to control for them as potential confounders. All linear model assumptions appear to be satisfied except for normality of the residual distribution (**Appendix**

B). In testing relevant model slopes for whether there was sufficient statistical evidence against the null hypothesis that the slope term equaled 0, we used a t-test with 9969 degrees of freedom at a pre-determined significance level of α = 0.05.

Results:

Table 1: Estimated regression coefficients for linear model

Model Term	***Estimate***	***Standard Error***	***P-value***
Intercept	8.908	0.145	<0.001
PHR Status			
Non-User	(Ref.)	-	-
User	-0.713	0.175	<0.001
Age (years)	-0.026	0.002	<0.001
Income (10000 US dollars)	-0.035	0.010	<0.001
BMI (kg/m^2)	0.010	0.002	<0.001
Race			
Non-Caucasian	(Ref.)	-	-
Caucasian	-0.207	0.035	<0.001
Sex			
Male	(Ref.)	-	-
Female	-0.094	0.029	0.001
PHR User * Age	0.007	0.003	0.013

At the α = 0.05 significance level, all fitted regression coefficients were statistically significant. Therefore, there is sufficient evidence to reject the null hypothesis and conclude that there is non-zero linear association between each of our predictors and HbA1c %, holding the other predictors constant. From our model, the expected HbA1c % is (0.713 - 0.007*Age) percentage points *lower* for a PHR user compared to a PHR nonuser, while adjusting for sex, race, income, and BMI, supporting our initial hypothesis. As our interaction term was statistically significant, we additionally conclude that there is sufficient statistical evidence suggesting that relationship between PHR user status and HbA1c % depends on the user's.

The positive regression coefficient for the interaction term between user status and age indicates that PHR usage by younger individuals is associated with a greater expected decrease in HbA1c % compared to PHR usage by older individuals, while holding all other predictors constant, again supporting our hypothesis. To get a sense of the difference using real ages from our dataset, estimated differences using various ages are provided in **Table 2**:

Table 2: Expected difference in HbA1c% by PHR usage status, adjusted for sex, race, income, and BMI

	19.3 (minimum)	***54.3 (Q1)***	***61.9 (median)***	***68.8 (Q3)***	***77.0 (maximum)***
Expected adjusted difference in HbA1c% in PHR users v. nonusers	-0.575%	-0.326%	-0.272%	-0.223%	-0.164%

Discussion:

Based on our analysis, we found sufficient evidence to conclude that PHR users have a lower expected HbA1c% than nonusers, while controlling for potential confounders, and that the magnitude of the expected difference in HbA1c% between users and nonusers depended on the user's age. Specifically, the magnitude of the expected difference in HbA1c% between users and nonusers is greater for a younger individual as opposed to an older individual. However, this observation is primarily clinically useful for large age differences (which is to say, *younger* *patients*). HbA1c% less than 5.7% is considered normal, and values between 5.7% and 6.5% are thought of as "pre-diabetes," with levels from 6.0% to 6.5% thought of as especially high risk. To use a concrete example, at the minimum age in our dataset (19.3 years, "young adult range"), the expected adjusted difference in HbA1c% is 0.575% lower in PHR users than non-users, which is potentially quite relevant. In contrast, for an older adult (age 65), this difference would be 0.258%, or approximately half the magnitude as that of a young adult.

Our results for the other predictors in our model are consistent with the existing literature. For example, the positive linear relationship between BMI and HbA1c%, while holding all other predictors constant, matched the literature findings which showed that blood glucose concentration increases with BMI (Sepp et al., 2014). Additionally, the lower expected HbA1c% in females compared to males, while holding all other predictors constant, matched recent findings of sex differences in blood glucose levels (Faerch et al., 2012). The trend of lower expected HbA1c% among whites (Carson et al., 2016) and the negative linear relationship observed between income and HbA1c% holding other predictors constant matches previous studies as well (Berkowitz et al., 2014).

An important limitation to consider when interpreting the results is that the assumption of normally distributed residuals was violated, as the residuals demonstrate slight right skew (**Appendix Figure B2**), and we also discarded a small amount of observations in our complete case analysis (2-3%). Additionally, HbA1c% was used as a proxy for the severity of diabetic status; however, HbA1c% is an imperfect measurement for truly diagnosing prediabetes or diabetes. In addition to the differences in clinical interpretation, many factors such as kidney failure, certain medicines, pregnancy, and blood loss can affect HbA1c results, falsely lowering or increasing the percentage (CDC, 2018). While we controlled for some potential confounders in our model, not all were measured and perhaps not all are known, limiting our ability to address this issue.

Future analyses could include more variables to consider as potential confounders, such as smoking status, and assess the impact of the frequency of PHR usage on HbA1c%. Additionally, to assess the generalizability of our results, we could repeat this analysis with other PHR datasets. Importantly, experimental studies should be conducted to assess a potential causative relationship between PHR usage and HbA1c%, assigning PHR usage/availability randomly among patients. This study only looked at associations between PHR usage and HbA1c% and thus it remains unclear if our observed associations were reflective of, say, someone who is generally more health conscious or the direct benefits of PHR. The use of a randomized trial in which some individuals are assigned to use their PHR and others are assigned not to would provide clarity on this issue.

In conclusion, our analysis found an association between an individual's usage of their Cleveland Health Clinic PHR and their health status, and that this association depended on the user's age. Despite our study finding that the magnitude of the expected reduction in HbA1c% associated with PHR usage decreased as the user's age increased, while controlling for other predictors, the usage of PHR still appears to be associated with a more positive health status for all studied ages. Whether this is reflective of someone who is generally more inclined to improve their health or the direct benefits of PHR remains to be determined and is beyond the scope of this study and the data available. As the world continues to modernize and healthcare increasingly relies on technology, findings such as this current study show that it is important to increase the technological literacy of the older populations especially in terms of electronic healthcare to ensure the best access and treatment for all who need it.

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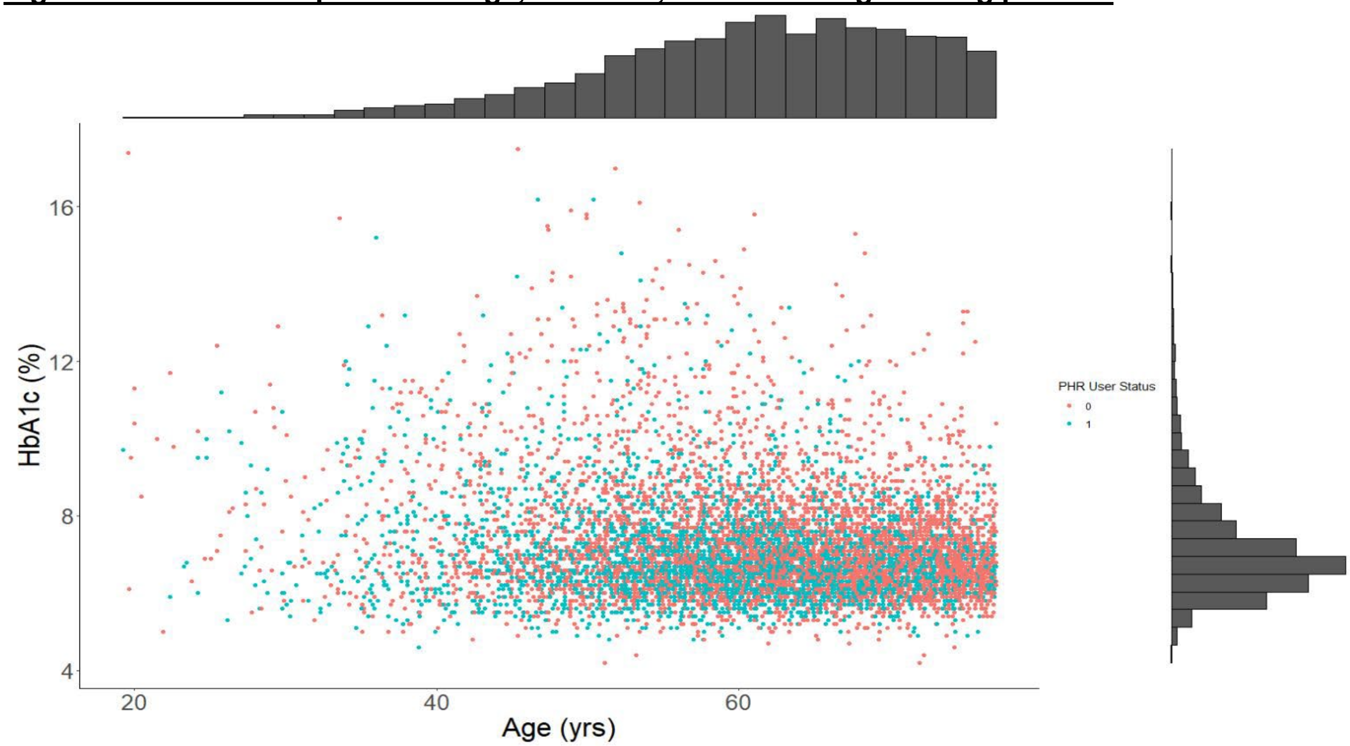
Appendix

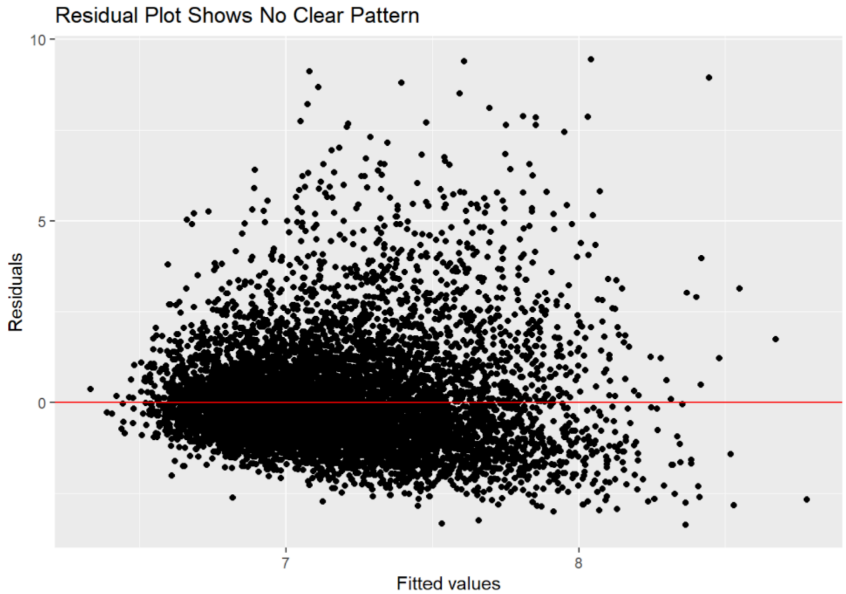
Figure A1: Relationship between age, HbA1C%, and PHR usage among patients



Assumptions for Linear Model ***PHR Usage and HbA1C %***

1. Independence.
   - The assumption of independence was met as the study contained data from Cleveland Clinic patients who were not related and thus the observations from one individual should not impact the observations for another.
2. Linearity
   - The assumption of linearity is met as the plotted residuals are mostly symmetric across the x-axis as demonstrated by the scatter plot in Figure A1.
3. Equal Variance
   - The assumption of homogeneity of variance is met as the range of residuals is mostly the same for all fitted values, as shown by the scatter plot in Figure A1 which shows no clear pattern.

Figure B1



4. Normally distributed residuals
    - The assumption of normally distributed residuals is not met in this analysis as the histogram of the residuals of this fitted model is right skewed (Figure A2).

Figure B2