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Research and Applications

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Patient judgments about hypertension control: the role of patient numeracy and graph literacy

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ABSTRACT

Objective: To assess the impact of patient health literacy, numeracy, and graph literacy on perceptions of hypertension control using different forms of data visualization.

Materials and Methods: Participants (Internet sample of 1079 patients with hypertension) reviewed 12 brief vignettes describing a fictitious patient; each vignette included a graph of the patient's blood pressure (BP) data. We examined how variations in mean systolic blood pressure, BP standard deviation, and form of visualization (eg, data table, graph with raw values or smoothed values only) affected judgments about hypertension control and need for medication change. We also measured patient's health literacy, subjective and objective numeracy, and graph literacy.

Results: Judgments about hypertension data presented as a smoothed graph were significantly more positive (ie, hypertension deemed to be better controlled) then judgments about the same data presented as either a data table or an unsmoothed graph. Hypertension data viewed in tabular form was perceived more positively than graphs of the raw data. Data visualization had the greatest impact on participants with high graph literacy.

Discussion: Data visualization can direct patients to attend to more clinically meaningful information, thereby improving their judgments of hypertension control. However, patients with lower graph literacy may still have difficulty accessing important information from data visualizations.

Conclusion: Addressing uncertainty inherent in the variability between BP measurements is an important consideration in visualization design. Well-designed data visualization could help to alleviate clinical uncertainty, one of the key drivers of clinical inertia and uncontrolled hypertension.

Key words: hypertension, data visualization, primary care, risk perception

INTRODUCTION

Uncontrolled hypertension is a significant health problem; in the United States alone, there are 75 million adults with diagnosed hypertension.[1,2,3] Hypertension control is an important goal in primary care because uncontrolled hypertension is a major risk factor for morbidity and mortality and contributes to heart disease, stroke, and chronic kidney disease.[2] National and regional health initiatives (eg, Healthy People 2020, Million Hearts Initiative, and Community Preventive Services Task Force) have focused on improving hypertension monitoring and management in both the clinic and home-based settings, and multiple drugs exist that effectively treat hypertension. Despite these efforts, hypertension remains uncontrolled in 48% of patients.[1,4–6]

Nonadherence to hypertension medication contributes to uncontrolled hypertension in about two-thirds of patients.[7] Nonadherence is likely a function of the complex interplay between a lack of clear, actionable guidance for patients, a patient's health literacy (ie, the ability to read and comprehend important health information),[8] and the healthcare system's failure to provide effective health communication materials (eg, medication labels, educational messaging) that match a patient's skill level.[9] Low patient health literacy is a significant predictor of refill non-adherence and has been broadly related to a reduced capacity for taking medication appropriately.[8–11] When our healthcare systems and interfaces are not designed with adequate health literacy supports in mind, patients are at a significant disadvantage.[9] For example, Kerr et al[12] reported that the primary reason for failing to intensify medication in a clinic visit was uncertainty about the "true" blood pressure (BP) value. Often when multiple BP measurements have been taken, individual readings fall both inside and outside the goal range leading physicians and patients to question which values have priority and therefore, if action is warranted. BP measurements occurring both within and above the goal range can be especially perplexing to patients, making decisions about BP control more difficult.[12–15] Pairing the clinical uncertainty associated with the measurement of hypertension and low health literacy common in the patient population leads to a decision context that is incredibly challenging for patients to navigate.

To improve hypertension control in the primary care setting, our research team developed a data visualization tool (ie, a visualization of key information, in this case BP data) designed to support shared decision-making for hypertension treatment between the patient and the physician during an office visit for hypertension.[16,17] The goals of this data visualization tool were to reduce clinical uncertainty around patient BP data and provide data in a more digestible form for patients with low health literacy. This tool is a graph of the patient's BP data over the last 24 consecutive months, embedded in the electronic health record (EHR), to be jointly viewed by the patient and clinician during a primary care office visit. It was developed via a rapid prototyping process in which candidate visualizations were iteratively refined based on regular feedback from patient and physician focus groups.[16,17]

During the prototype development process, we conducted a series of vignette-based pilot studies, which revealed that patients' judgments of hypertension control were significantly influenced by mean BP value, standard deviation (SD), trends in the data, and outliers.[18] While attending to the average BP is beneficial because it is the most important predictor of hypertension-related health out-

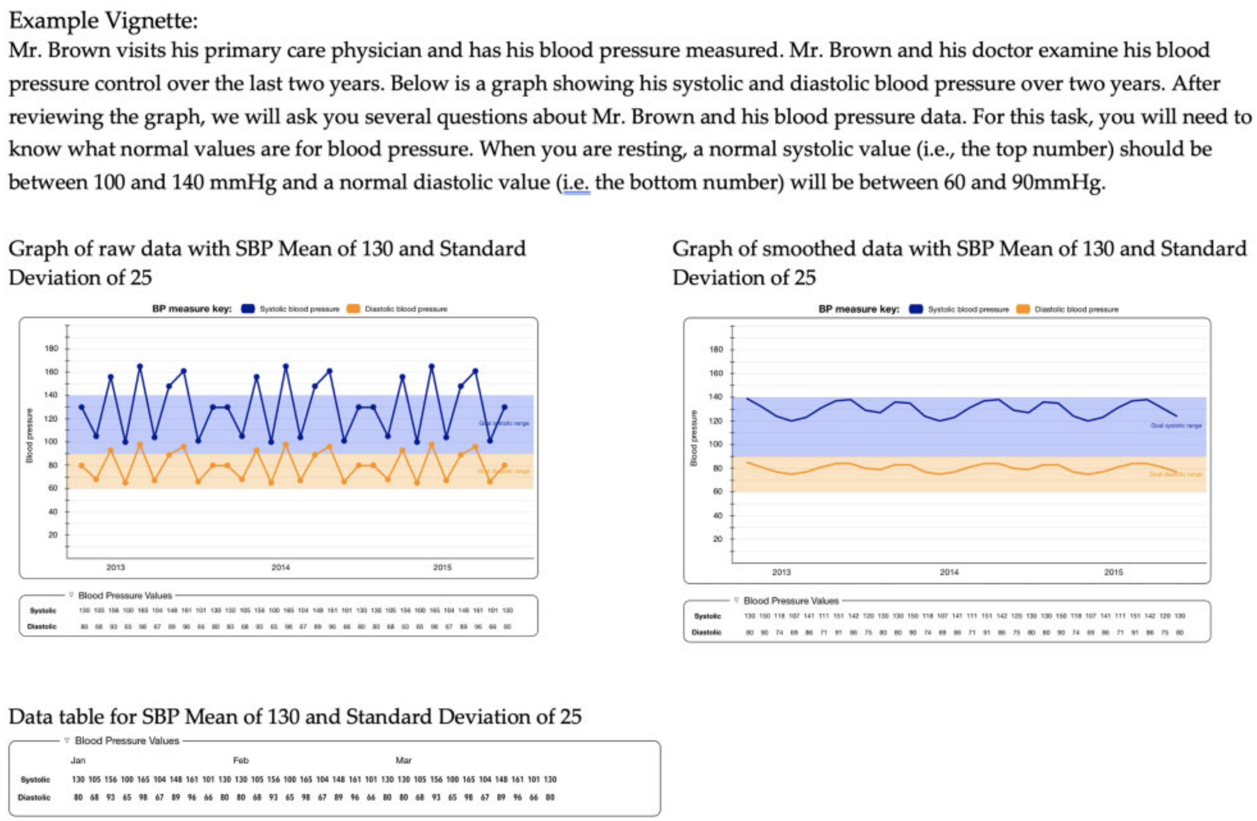

Figure 1. Example of vignette and data visualization tools.

Table 1. Descriptive statistics for the primary outcomes

	Graph with raw data	Data table	Graph with smoothed data	Test statistic	Value	P	ω^2 (95% CI)
This patient's blood pressure is well controlled.				SBP mean: F (1, 1078)	1054.92	<.001	.49
(0 "Strongly Disagree"–100 "Strongly Agree")							(0.45, 0.54)
SBP mean 130				SBP SD: F (1, 1078)	565.21	<.001	.34
SD 15	54.0 (29.5)	62.9 (26.2)	74.9 (24.8)				(0.30, 0.39)
SD 25	38.8 (32.0)	52.6 (29.1)	71.2 (26.7)				
SBP mean 145				Visualization type: F (2, 2156)	541.80	<.001	.72
SD 15	37.0 (30.0)	46.0 (28.3)	51.5 (28.8)				(0.70, 0.74)
SD 25	29.4 (30.7)	39.4 (30.0)	37.4 (29.8)				
This patient needs to change their medication.				SBP mean: F (1, 1078)	1161.44	<.001	.52
(0 "Strongly Disagree"–100 "Strongly Agree")							(0.48, 0.56)
SBP mean 130				SBP SD: F (1, 1078)	514.90	<.001	.32
SD 15	55.8 (29.4)	47.5 (29.9)	34.7 (31.6)				(0.28, 0.37)
SD 25	71.8 (26.6)	57.9 (28.1)	37.8 (31.5)				
SBP mean 145				Visualization type: F (2, 2156)	524.40	<.001	.33
SD 15	73.1 (23.6)	65.3 (25.1)	61.3 (27.2)				(0.29, 0.36)
SD 25	80.2 (22.2)	71.1 (24.1)	73.0 (22.7)				
How well do you understand what this blood pressure data means for this patient's health?				SBP mean: F (1, 1078)	17.12	<.001	.01
(0 "Not At All"–6 "Completely")							(0.00, 0.03)
SBP mean 130				SBP SD: F (1, 1078)	0.29	.59	.00
SD 15	4.40 (1.34)	4.44 (1.31)	4.65 (1.30)				(0.00, 1.00)
SD 25	4.41 (1.39)	4.30 (1.36)	4.66 (1.28)				
SBP mean 145				Visualization type: F (2, 2156)	38.59	<.001	.03
SD 15	4.44 (1.35)	4.35 (1.30)	4.42 (1.33)				(0.02, 0.05)
SD 25	4.52 (1.36)	4.37 (1.33)	4.39 (1.33)				
How alarming is this blood pressure data?				SBP mean: F (1, 1078)	1086.63	<.001	.50
(0 "Not Alarming At All"–6 "Very Alarming")							(0.46, 0.54)
SBP mean 130				SBP SD: F (1, 1078)	620.40	<.001	.36
SD 15	3.26 (1.72)	2.79 (1.72)	2.13 (1.88)				(0.32, 0.41)
SD 25	4.24 (1.54)	3.34 (1.62)	2.32 (1.87)				
SBP mean 145				Visualization type: F (2, 2156)	538.60	<.001	.33
SD 15	4.27 (1.40)	3.72 (1.50)	3.53 (1.58)				(0.30, 0.36)
SD 25	4.79 (1.30)	4.13 (1.42)	4.24 (1.35)				

Note: Data are expressed as mean (SD).
CI: confidence interval; SBP: systolic blood pressure; SD: standard deviation.

comes, attending to the variation and outliers present in BP data is a potential distraction for patients.[19] For example, patients perceived BP data that were highly variable as uncontrolled, even if the mean systolic blood pressure (SBP) was in the goal range. These results from our early studies are consistent with other work demonstrating that humans selectively overweight large numbers during numerical comprehension tasks.[20] This led us to develop additional prototype displays that included a line representing a rolling average of BP based on a smoothing function.[21] The smoothing line was generated by a locally weighted smoothing algorithm that employs a local regression technique to smooth the data by presenting an average value within a given interval size.[21] Further pilot testing of these prototype displays demonstrated that enhanced data displays, which employed a smoothing function, directed patient attention to clinically meaningful elements of the display and led to judgments about hypertension control were generally more consistent with clinical guidelines.[21–23]

In this article, we report the results of a large patient study that was designed to examine how numeracy and literacy interact with visualization formats to impact judgments of hypertension control. Individual differences in health literacy, numeracy, and graph literacy are crucial to our understanding of the impact of graphical displays. Health literacy may impact a patient's ability to understand written materials related to the treatment of their hypertension[8] and, in turn, can affect perceptions of need for care and treatment decisions, which will ultimately impact health and well-being. Numeracy—the ability to utilize and understand numerical information—may be particularly important for hypertensive patients as they work to understand and interpret numbers relevant to their treatment.[24,25] Specifically, patients will need to make use of individual BP data containing wide variation, interpret how that data fits into their goal range, and understand how that information informs their risk of negative health outcomes (eg, heart attack and stroke). One posited solution for patients with low health literacy or low numeracy is the use of graphical displays to improve comprehension of risk information.[26,27] Therefore, graph literacy—the ability to understand and interpret graphs—is also likely to be an important predictor of the ability to extract information from visualizations.[28] While health literacy is associated with graph literacy and numeracy, one study has shown that graph literacy is predictive of performance on health management tasks even after taking these other variables into account.[29] Additionally, if different ways of visualizing BP data lead to different conclusions about BP control, this may impact decisions about how data are presented, including any potential differential effect for those with varying levels of literacy and numeracy.

METHODS

Study design

This study was designed to assess the impact of health literacy, numeracy, and graph literacy on perceptions of hypertension control using different forms of data visualization. An Internet sample of patients with hypertension reviewed several brief vignettes describing a fictitious patient; each vignette included a graph of the patient's BP data. This work was reviewed and approved by the Institutional Review Board affiliated with the first author's home institution. All participants were recruited by Qualtrics, a survey company that maintains an opt-in demographically diverse Internet panel that participates in survey research in exchange for small incentives. Participants with hypertension were identified via a single self-reported measure: "Has your doctor ever diagnosed you with hypertension, also known as high blood pressure?"; similar self-report items have been used to identify patients with hypertension in other epidemiologic studies.[30–33]

Each vignette described a patient being treated for hypertension and included a visualization of the patient's BP data over the past 2 years. See Figure 1 for vignette details and an example of the data visualization tool. There were 12 vignettes that systematically varied in the mean SBP (130 and 145 mmHg), BP SD (15 and 25), and form of data visualization (data table, graph with raw, or smoothed values). Mean SBP was chosen to represent clinical cases that included examples of controlled (mean SBP = 130 mmHg) and uncontrolled (mean SBP = 145 mmHg) hypertension according to the 2014 Hypertension Management Guideline.[34] The SDs were chosen to represent moderate and large mean variability according to published SBP values.[35] The study used a 2 (SBP mean) × 2 (SBP SD) × 3 (data visualization type) within-subjects design, where all participants reviewed all vignettes, presented in random order, and provided judgments about the degree of hypertension control for every patient/vignette.

Using this vignette-based method, where patients with hypertension review data from other cases, has the benefit of allowing us to systematically manipulate characteristics of the data that may not be present within data from a single patient (ie, BP in the controlled range in one example and in the uncontrolled range in another example). This enables us to better assess accuracy in judgments about hypertension control. Further, while the task of assessing hypertension control and need for medication change is typically the responsibility of the clinician, patients are more likely to be adherent to medication, diet, and lifestyle changes associated with the treatment of hypertension if they can understand how these changes are affecting their health.[36] Home BP monitoring is also an increasingly common task, and several patient-facing applications for mobile devices exist to help patients record and track their BP over time. In such cases, the patients will be responsible for seeking out additional treatment based on their data as needed.

Outcomes

Primary outcomes were: (1) perceived BP control, (2) need for medication change, (3) understanding of what the BP data meant for the patient's health, and (4) how alarming the BP data was for each vignette. See Table 1 for item wording and scale ranges. These items were chosen to capture the effect of the different attributes manipulated in the vignettes (eg, mean SBP, SD, data visualization type) on the accuracy of patient perceptions about hypertension control. For example, in vignettes where the mean SBP was 130 mmHg, patients should generally report that the patient's hypertension was controlled

Table 2. Participant characteristics

Participant characteristics	
N	1079
Gender, *N* (%)	
Male	375 (34.8)
Female	704 (65.2)
Age, mean (SD)	53.70 (15.56)
Age range	18–99
Race/Ethnicity, *N* (%)	
White	844 (78.2)
Black	135 (12.5)
Asian/Pacific Islander	31 (2.87)
American Indian/Alaskan Native	13 (1.2)
Hispanic or Latinx	0
Multiracial/ethnic	35 (3.24)
Other	21 (1.94)
Single Item Literacy Screener for health literacy (SILS), mean (SD)	0.6645 (0.4724)
Subjective Numeracy Scale (SNS), *N* (%) low health literacy	4.129 (1.082)
Berlin Numeracy, mean (SD)	0.3253 (0.535)
Graph Literacy, mean (SD)	7.639 (3.425)
Education, *N* (%)	
Some high school	36 (3.34)
High school graduate	247 (22.9)
Some college	235 (21.8)
Vocational training	52 (4.82)
Associates degree	136 (12.6)
Bachelor's degree	237 (22)
Master's degree	95 (8.8)
Professional degree	25 (2.31)
Doctoral degree	16 (1.48)
Income ($ USD), *N* (%)	
Less than 10k	84 (7.78)
10–19k	122 (11.3)
20–29k	165 (15.3)
30–39k	146 (13.5)
40–49k	109 (10.1)
50–59k	92 (8.53)
60–69k	66 (6.12)
70–79k	76 (7.04)
80–89k	43 (4)
90–99k	40 (3.7)
100–149k	87 (8.07)
Above 149k	49 (4.54)
How often do you monitor your BP at home?, *N* (%)	
Never	271 (25.1)
Annually	111 (10.3)
Monthly	248 (23)
Weekly	265 (24.6)
Daily	184 (17.1)
How often do you graph your home BP measurements?, *N* (%)	
Never	713 (66.1)
Annually	63 (5.84)
Monthly	107 (9.91)
Weekly	125 (11.6)
Daily	71 (6.58)

BP: blood pressure; SD: standard deviation.

and there was little need for medication change. In contrast, patients should report much lower ratings of hypertension control and higher scores on need for medication change for vignettes where the mean SBP was 145 mmHg. Further, holding mean SBP and SD constant, we can compare whether presenting the data in different visualization forms (eg, table, graph of raw data, graph with smoothing function) altered patients' perceptions of hypertension control.

After evaluating all vignettes, participants were also asked to compare the 3 different visualizations on helpfulness, trustworthiness, usefulness, and preference. Participants then were asked to rate for each visualization on a 1–100, "Very Low" to "Very High" scale on how mentally demanding the task was, how successful they were at completing it, how hard they had to work to complete it, and how much frustration they felt at the task. Then, participants completed the Graph Literacy Scale[28]—a measure of one's ability to understanding information which has been presented graphically (ie, data visualizations), the Subjective Numeracy Scale (SNS)[37]—a self-assessed measure of one's ability to perform various mathematical operations (eg, calculating a 15% tip), the Berlin Numeracy Test[38]—an objective measure of one's statistical abilities and risk literacy, and the Single Item Literacy Screener for health literacy (SILS)[8]—a measure of how much help one needs in understanding written material from their doctor or pharmacist. Participants also provided demographic information and responded to additional items about how often they monitor and graph their own BP.

Power and statistical analyses

We planned to recruit 1000 patients with hypertension. Sample size was determined *a priori* using G-Power,[39,40] with the following data characteristics: greater than 90% power to detect a significant small-sized effect (Cohen's $f = 0.10$) at an alpha level of .05, with a minimum correlation of .50 between repeated measures. All outcomes were treated as continuous variables. We examined the effects of SBP mean, SBP SD, and data visualization type on all primary outcomes (perceived hypertension control, need for medication change, perceived comprehension, and alarm) by conducting a series of analysis of variance tests for repeated measures. We examined main effects, 2-way interactions, and 3-way interactions. To examine the research questions about the moderating role of individual differences, we used a series of mixed-effects models to examine the influence of subjective numeracy, objective numeracy, graph literacy, and health literacy on our 4 primary outcomes. We tested models with both random and fixed intercepts and slopes with each outcome as the Level 1 variable and participant as the Level 2 variable. Fixed effects included level of SBP mean, SBP SD, and format of data visualization. Measures of numeracy and graph literacy were included as level 2 predictors. The best models as judged by Akaike Information Criteria and Bayesian Information Criteria are described below. All tests were conducted using R version 4.0.3 and were considered statistically significant when $P < .05$.[41] Linear mixed models were fit using the lme4 package in R.[42]

RESULTS

Participants

An Internet sample of 1079 patients with hypertension participated in this study. Participants were majority female (65%) and White (78.2%), with a mean age of 53.70 years (SD = 15.56), and 26.2% having a maximum education level of high school or less. See Table 2 for additional participant characteristics.

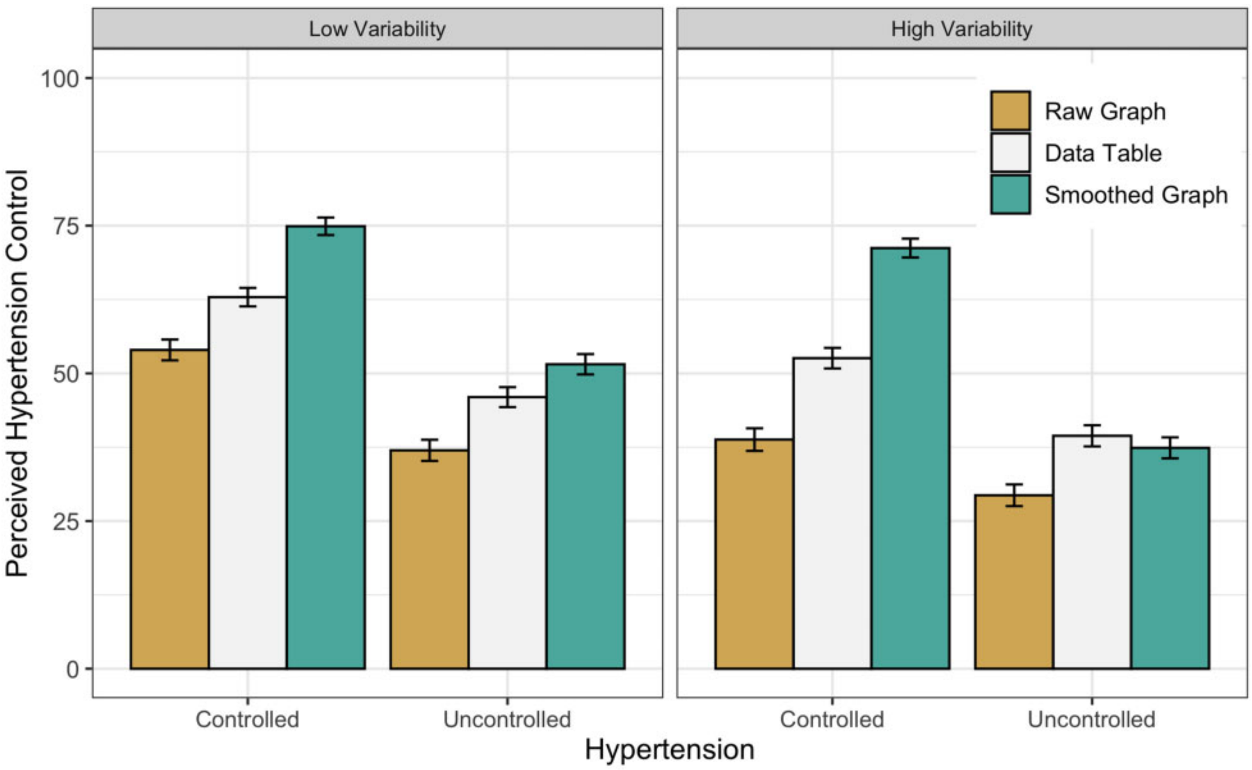

Figure 2. The effects of blood pressure mean, standard deviation, and data visualization type on judgments of hypertension control.

Confirming our prior research in smaller samples,[18,21] we observed a significant main effect of SBP mean on perceptions of hypertension control, need for medication change, perceived comprehension, and alarm. Judgments of hypertension control and perceived comprehension were greater for vignettes depicting patients with controlled hypertension, while need for medication and alarm were rated lower; see Table 1. We also observed a significant main effect of SBP SD on perceived BP control, need for medication change, and alarm but not for perceived comprehension. Judgments of hypertension control were lower and judgments of perceived need for medication change and alarm were higher when SBP variability was high (SD = 25 mmHg) compared to when it was low (SD = 15 mmHg).

There was also a significant main effect of data visualization type on perceptions of hypertension control, need for medication change, perceived comprehension, and alarm. Judgments about hypertension data presented as a graph with a smoothing function were significantly more positive (ie, participants judged hypertension to be better controlled and were less alarmed) then judgments about the same data presented as either a data table or a graph of the raw data. Further, hypertension data viewed in tabular form was generally perceived to be more positive than in graphs of the raw data.

These main effects are qualified by significant 3-way interactions between SBP mean, SBP SD, and data visualization type on all 4 primary outcomes: perceived hypertension control (F [2, 2156] = 61.51, $P < .001$, $\omega^2 = .05$, 95% confidence interval [CI] [0.04, 0.07]), need for medication change (F [2, 2156] = 64.8, $P < .001$, $\omega^2 = .06$, 95% CI [0.04, 0.08]), perceived comprehension (F [2, 2156] = 5.92, $P = .003$, $\omega^2 = .00$, 95% CI [0.00, 0.01]), and alarm (F [2, 2156] = 59.96, $P < .001$, $\omega^2 = .05$, 95% CI [0.03, 0.07]). These 3-way interactions reveal that differences in judgments between methods of data visualization are greatest when hypertension is controlled (ie, SBP mean = 130). However, when hypertension is uncontrolled (ie, SBP mean = 145) and SBP variability is maximal (ie, SBP SD = 25), participant judgments are uniformly negative; see Figure 2.

Further, graph literacy, subjective numeracy, and health literacy were all significant predictors of all 4 primary outcomes, while objective numeracy was not. Parameter estimates for the adjusted hierarchical model of perceived hypertension control are provided in Table 3. Graph literacy and health literacy were negatively related to perceived hypertension control and positively related to need for medication change, while subjective numeracy was positively related to perceived hypertension control and negatively related to need for medication change. Figure 3 shows the relationship between graph literacy, data visualization type, and SBP mean. Patients with the lowest levels of graph literacy are unable to distinguish between cases of controlled and uncontrolled hypertension with any form of data visualization. However, patients with higher levels of graph literacy were able to better discriminate between controlled and uncontrolled hypertension cases. Further, data visualization type provided the greatest benefit in cases where hypertension was controlled. Participants with high graph literacy provided the most accurate judgments of hypertension control in "controlled" cases using a graph with the smoothing function and least accurate using a graph of the raw data.

Table 3. Parameter estimates for the adjusted hierarchical model of perceived hypertension control

Parameter	β	Standard error	P
(Intercept)	62.12	2.15	<.001
Data visualization type			
Graph of raw data	<Reference>		
Data table	8.94	0.94	<.001
Graph with smoothing function	20.94	0.99	<.001
SBP mean			
130	<Reference>		
145	−16.99	0.99	<.001
SBP standard deviation			
15	<Reference>		
25	−15.17	0.89	<.001
Graph Literacy	−1.52	0.17	<.001
Subjective numeracy	2.31	0.46	<.001
Single Item Health Literacy Screener	−8.22	1.12	<.001
Berlin Numeracy	−1.79	0.98	.069
Visualization × SBP mean interactions			
Graph raw data × SBP 130	<Reference>		
Data table × SBP 145	0.07	1.23	.95
Graph smoothing × SBP 145	−6.37	1.23	<.001
Visualization × SBP SD interactions			
Graph raw data × SD 15	<Reference>		
Data table × SD 25	4.84	1.23	<.001
Graph smoothing × SD 25	11.49	1.23	<.001
SBP mean × SBP SD interactions			
SBP 130 × SD 15	<Reference>		
SBP 145 × SD 25	7.57	1.23	<.001
Visualization × mean × SD			
Graph raw × SBP 130 × SD 15	<Reference>		
Data table × SBP 145 × SD 25	−3.78	1.74	.02
Graph smoothing × SBP 145 × SD 25	−18.02	1.74	<.001

BP: blood pressure; SD: standard deviation.

DISCUSSION

To inform the development of a physician-patient shared data visualization tool for hypertension, we conducted a vignette-based study to understand how the format of data visualization influences patient interpretation of hypertension control. Patients with hypertension consistently judged data presented in a graph with only a smoothing function more positively than either a graph of the raw data or data presented in tabular form. Numeracy, health literacy, and graph literacy significantly impacted the ability to extract meaningful information from data visualizations. Patients with lower levels of graph literacy could not discriminate between controlled and uncontrolled cases of hypertension regardless of data visualization. Discrimination between cases was greatest for patients with high graph literacy when using the smoothed graph.

The nature of BP data is inherently variable; addressing uncertainty based on this variability is an important consideration in visualization design. Well-designed data visualization could help to alleviate clinical uncertainty, one of the key drivers of clinical inertia and uncontrolled hypertension.[12] Additionally, patient-generated home BP data are becoming a more important part of clinical decision-making and can potentially result in a torrent of data; effective data visualization for BP data is increasingly crucial to integrate this data into the EHR and clinical workflow.[16–18] An understanding of the results of this study should shape those data visualizations. For example, knowing that patients rate more variable BP as more

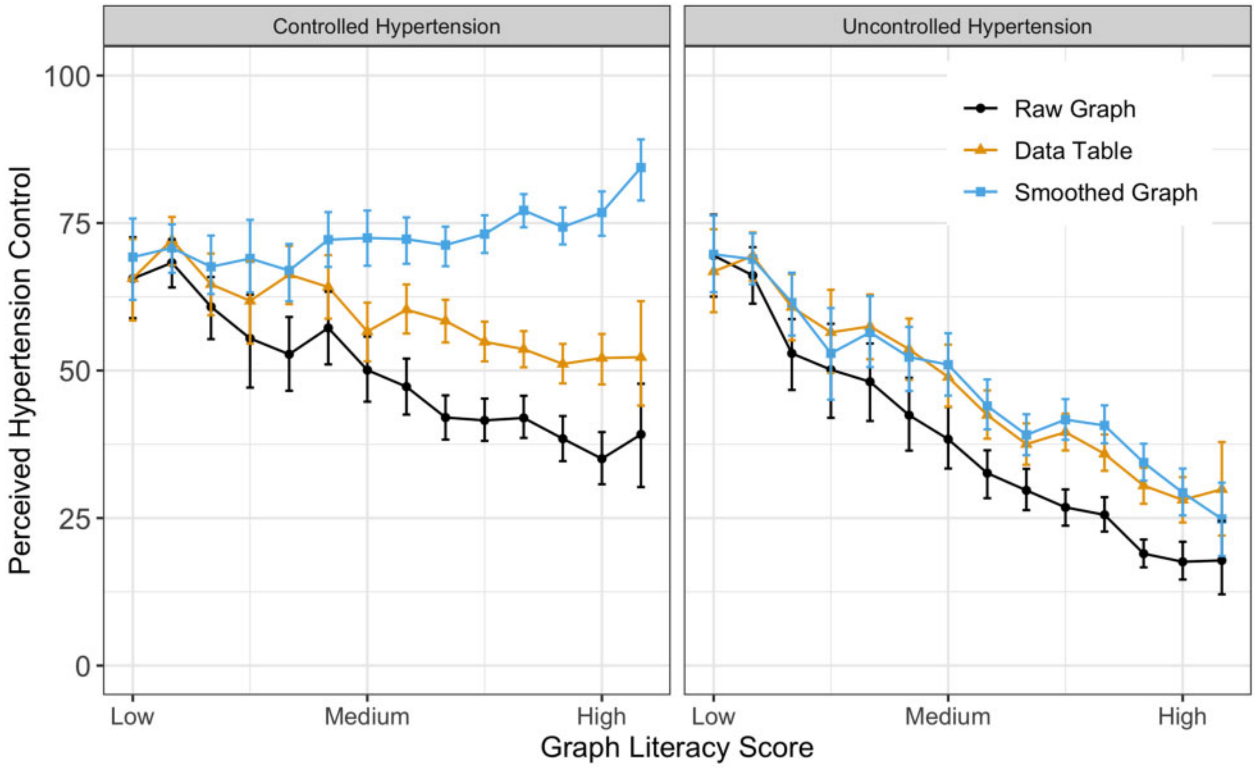

Figure 3. The interaction between graph literacy and data visualization type on judgments about hypertension control: discrimination between uncontrolled and controlled hypertension is improved with the smoothing function for patients with high graph literacy.

uncontrolled, even if the mean is in the goal range, led us to include in our BP display a line representing a rolling average of BP based on a smoothing function.[21] Viewing "smoothed" data may also require an adjustment in approach for clinicians and patients as a smoothed line just above the goal range should be less easily dismissed as "close to goal" than individual data points. Finally, our findings that tabular displays of data are viewed more positively than graphs of that same data may indicate a positive bias in viewing raw BP data. Choice of data visualization for BP data should incorporate these findings.

There are limitations to this study that potentially reduce generalizability. One limitation is the use of Internet patient samples given that decisions about treatment for hypertension are typically made in conjunction with physicians during clinic visits. Additionally, while our sample of patients is more demographically diverse than typical Internet samples, it is not representative of the population of patients with hypertension. The prevalence of hypertension is greater in men than women, but 65% of our sample was comprised of women.[43] High BP is also more common among non-Hispanic Black adults than non-Hispanic White adults,[43] and only 12.5% of our sample self-identified as Black. Further, Internet samples are likely to have higher literacy and numeracy than the general population. Finally, we focused only on patients in these studies; future work should examine the effect of data visualization on physicians' judgments about hypertension control, as well as on shared decisions. Physicians may perform similarly to patients due to common perceptual and cognitive processes affecting judgment.[44,45] Alternatively, physicians could perform better due to greater knowledge about the relative importance of BP mean and variability and likely greater levels of graph literacy consistent with their training.

Health information technologies provide an opportunity for patients to become more engaged in decision-making about hypertension control. Defining how data elements (ie, variability) and visualization type (ie, table vs graph) support or detract from an understanding of data has aided in the design of visualizations that highlight meaningful characteristics. This work has informed the development of visualizations for treatment of hypertension that can be used by physicians and patients together to make better decisions.[14,17] As we begin to include home BP in clinical care and decision-making, the results of this study can be used to inform the design of effective data visualizations for potentially copious home BP data. In our own data visualization design, these results led us to decide to provide a balanced and transparent view of both smoothed and raw data, with the option to subtract the smoothed line and view only raw data. Areas for future study include understanding how these parameters influence physician judgments about hypertension control, exploring alternative modalities for presenting patient data, and tailoring data visualizations for different levels of patient numeracy, health literacy, and graph literacy. Future work should also focus on the impact of data visualization in under-resourced communities as the impact of numeracy and literacy may be greater for these populations.

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AUTHOR CONTRIBUTIONS

VAS made substantial contributions to the research design, data analysis, and interpretation of the data as well as drafting the manuscript, its revision, and the final approval of the version to be published. VAS and RJK agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. PW, KDV, SMC, JLB, LMS, MP, and RJK also contributed to the research design, data interpretation, and critical revision of the manuscript. SD contributed to the data analyses, interpretation of the data, and drafting the manuscript.

CONFLICT OF INTEREST STATEMENT

None declared.

DATA AVAILABILITY

Data are available in a repository and can be accessed using a unique identifier other than a DOI. The data are available at this link for peer review: https://osf.io/asf2m/?view_only=289e1a3d0b504c498681b5959b7e77c2.

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