The Relationships Between Health Information Behavior and Neural Processing in African Americans With Prehypertension

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Information behavior may enhance hypertension self-management in African Americans. The goal of this substudy was to examine the relationships between measures of self-reported health information behavior and neural measures of health information processing in a sample of 19 prehypertensive African Americans (mean age = 52.5, 52.6% women). We measured (a) health information seeking, sharing, and use (surveys) and (b) neural activity using functional magnetic resonance imaging (fMRI) to assess response to health information videos. We hypothesized that differential activation (comparison of analytic vs. empathic brain activity when watching a specific type of video) would indicate better function in three, distinct cognitive domains: (a) Analytic Network, (b) Default Mode Network (DMN), and (c) ventromedial prefrontal cortex (vmPFC). Scores on the information sharing measure (but not seeking or use) were positively associated with differential activation in the vmPFC

Received November 14, 2017; revised May 21, 2018; accepted June 11, 2018

© 2018 ASIS&T • Published online November 23, 2018 in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/asi.24098

(rs = .53, *p* = .02) and the DMN (rs = .43, *p* = .06). Our findings correspond with previous work indicating that activation of the DMN and vmPFC is associated with sharing information to persuade others and with behavior change. Although health information is commonly conveyed as detached and analytic in nature, our findings suggest that neural processing of socially and emotionally salient health information is more closely associated with health information sharing.

Introduction

Diagnosed hypertension is prevalent among African Americans (Mozaffarian et al., 2016). Living with uncontrolled blood pressure can lead to negative outcomes, including end-stage renal disease, stroke, myocardial infarction, or death (Chobanian et al., 2003). Therefore, assisting African Americans to reduce elevated and maintain normotensive blood pressure (<140/90 mmHg) has important public health relevance. One way to address this problem is to intervene early if patients reach the level of "prehypertension" (>120/79 mmHg). Self-management behaviors help patients control high blood pressure; this may prevent the progression of prehypertension into frank hypertension (Whelton et al., 2002). According to Ryan and Sawin (2009), self-management consists of using knowledge, skills, and social facilitators to manage chronic conditions and engage in healthy behaviors. Such self-management of elevated blood pressure typically entails patients finding, interpreting, and using blood pressure-related health information. In addition, African Americans' self-management behavior is associated with sharing of information with peers, or other lay people who have hypertension, or are at risk for the condition (Jones, Veinot, Pressler, Coleman-Burns, & McCall, 2017; Jones, Wright, Wallace, & Veinot, 2017). Research conducted with African American patients with chronic illness highlights the need for targeted interventions that support health information behavior to enhance self-management (Jones, Veinot, Pressler, Coleman-Burns, et al., 2017; Kaziunas, Ackerman, & Veinot, 2013).

One way to potentially optimize blood pressure self-management interventions in African Americans is to inform these programs with findings from basic and translational neuroscience investigating the mechanisms associated with health information behavior and change (Whelan, Morgan, Sherar, Orme, & Esliger, 2017). Furthermore, understanding the neural mechanisms of information behaviors can advance the foundations of the discipline. Although researchers have examined the relationships between information behavior and health behavior (Jones, Veinot, & Pressler, 2017; Meadowbrooke, Veinot, Loveluck, Hickok, & Bauermeister, 2014; Veinot, Meadowbrooke, Loveluck, Hickok, & Bauermeister, 2013), few studies have investigated the neural mechanisms underlying similar health information behavior (Moshfeghi, Pinto, Pollick, & Jose, 2013; Moshfeghi, Triantafillou, & Pollick, 2016). The purpose of this substudy was to explore the relationships among information behavior (seeking, sharing, and use, via self-report) and patterns of neural activation when individuals receive two types of health information (analytic and empathic). The current study builds upon prior work that implicated these areas as crucial to effective information sharing and in behavior change (for instance, Falk & Bassett, 2017; Falk, Berkman, Whalen, & Lieberman, 2011; Whelan et al., 2017).

Health Information Behavior

Health information is a critical resource for people with, or at risk of developing chronic illnesses. Information use refers to the application of information to help resolve a problem such as illness (Kari, 2010). Effective utilization of health information can help individuals make decisions (Fox, 2009; Livneh & Martz, 2007); solve problems (Endler & Parker, 1994; Farber, Mirsalimi, Williams, & McDaniel, 2003; Folkman & Greer, 2000; Stanton, Revenson, & Tennen, 2007); pursue or coordinate new lines of action (Schaefer, Coyne, & Lazarus, 1981; Siegel & Krauss, 1991; Skinner, Edge, Altman, & Sherwood, 2003); use resources more effectively (Moos & Tsu, 1977); gain emotional comfort (Chen, 2015; Rubenstein, 2015; Wolf & Veinot, 2015); and change their behavior (Case, 2012; Fox, 2009; Greyson & Johnson, 2015; Jones, Wright, et al., 2017). Each of these forms of help contribute to effective disease self-management and health promotion.

To promote blood pressure self-management, healthcare professionals frequently provide verbal and written information to inform patients and to respond to patient questions (Souden & Durrance, 2011). Information seeking refers to actions taken by individuals to obtain the necessary information to resolve a need, such as a health concern (Case, 2012; Lambert & Loiselle, 2007). Patients frequently seek, share, and produce information outside of the healthcare setting (Costello & Costello, 2017; Rubenstein, 2015; St Jean, 2017; Veinot et al., 2013; Wolf & Veinot, 2015). Information sharing refers to an exchange of information whether conveyed implicitly or explicitly, and may have fuzzy to well-defined goals (Talja & Hansen, 2006)—particularly in an everyday illness context (Veinot, 2009). An example of health information sharing is an individual conveying information on how to self-manage blood pressure (for instance, diet and exercise) to family members or friends (Fisher & McKechnie, 2005; Greyson & Johnson, 2015). Health information sharing may be motivated by altruism, relationship building, enjoyment, self-presentational needs, and the desire to influence the health behavior of others (Abrahamson, Fisher, Turner, Durrance, & Turner, 2008; Veinot, Kim, & Meadowbrooke, 2011; Wolf & Veinot, 2015; Ziebland & Wyke, 2012). Notably, although it has not yet been the subject of direct study, information sharing itself may have health implications. As our previous work indicates, African American women with hypertension who shared information about blood pressure management with other lay people were more likely to report using information to self-manage their own blood pressure (Jones, Veinot, & Pressler, 2017; Jones, Veinot, Pressler, Coleman-Burns, et al., 2017). HIV testing

DOI: 10.1002/asi

behavior may also be linked to information sharing (Veinot et al., 2013). Participants also preferred to share with family members and peers with whom they already had close relationships (Abrahamson et al., 2008; Cutrona et al., 2016; Jones, Veinot, Pressler, Coleman-Burns, et al., 2017).

Although this work illustrates the value of health information behaviors, especially as it relates to African American women, little is known about the neural processes underlying health information behavior. A few information science pilot studies have examined neural processes associated with searching behavior when interacting with information retrieval systems. Mostafa, Carrasco, Foster, and Giovenallo (2015) asked participants to review displays of search results that varied both in terms of the type of question asked (factual vs. topical) and the precision of the results. Findings for brain areas associated with the factual questions were broadly consistent with brain areas associated with the factual condition used in this study. Similarly, Mostafa and Gwizdka (2016) found that participants were presented with both relevant and irrelevant search results; the findings showed that this task activated the middle frontal gyrus, a part of the Analytic Network associated with decision-making. Despite these early advances, there remain gaps in understanding neurological processes underlying a range of information behaviors and their possible connections to health behaviors. Therefore, following growing interest in the field of information science (Gwizdka & Mostafa, 2017; Maior, Pike, Sharples, & Wilson, 2015; Mostafa & Gwizdka, 2016; O'Brien, Gwizdka, Lopatovska, & Mostafa, 2015), we investigated relationships between information seeking, sharing, and use and the Default Mode Network (DMN) and Analytic Network.

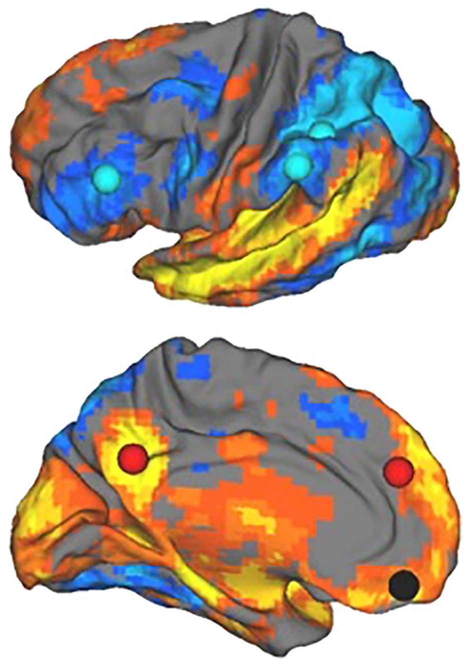

FIG. 1. Contrast between Coping Stories (orange/yellow) and Fact Focused (blue) conditions (CS-FF). A priori determined regions of interest are illustrated by spheres: turquoise, Analytic Network, red, Empathy Network, Black, vmPFC. Dorsal-lateral and medial surfaces of the left hemisphere are shown, with data projected onto the PALS average surface atlas. [Color figure can be viewed at wileyonlinelibrary.com]

Cognitive Neuroscience of Health Information Behavior

The empathy network. The Empathy Network is comprised of parts of the medial parietal cortex and neighboring posterior cingulate, dorsal medial prefrontal cortex, and temporo-parietal junction (Fox et al., 2005; Schilbach et al., 2012; Schilbach, Eickhoff, Rotarska-Jagiela, Fink, & Vogeley, 2008; Figure 1). The same set of brain regions are also known by other labels, such as the "Mentalizing network" (Amodio & Frith, 2006), "Social Brain" (Mars et al., 2012), and the DMN (Raichle & Snyder, 2007). Notably, these brain regions correspond to the more dorsal (or superior) parts of the DMN. The theoretical and empirical data motivating the term "Empathy Network" have been explained at length elsewhere (Boyatzis, Rochford, & Jack, 2014; Friedman, Jack, Rochford, & Boyatzis, 2015; Jack et al., 2013; Jack, Friedman, Boyatzis, & Taylor, 2016). The Empathy Network is strongly associated with social and emotional cognition, including "Cognitive Empathy" aka "Mentalizing" or "Theory of Mind," that is, thinking about one's own and others' thoughts and feelings (Denny, Kober, Wager, & Ochsner, 2012), emotion regulation and safety signaling (Marstaller, Burianová, & Reutens, 2016), receiving and providing social support (Eisenberger & Cole, 2012), empathizing with others (Powers, Chavez, & Heatherton, 2015; Rameson, Morelli, & Lieberman, 2012), and evaluating the personal and social relevance of information (Bartra, McGuire, & Kable, 2013).

The ventral medial prefrontal cortex (vmPFC). The key region of the ventral DMN, located in the lower areas of the DMN, is the vmPFC (Figure 1). It is involved in motivational, emotional, and parasympathetic processing, as well as autobiographical memory; hence, it has been described as the neural area responsible for generating "affective meaning" (Roy, Shohamy, & Wager, 2012). The vmPFC mediates links between social connection and health (Eisenberger & Cole, 2012). Activation of the vmPFC is robustly associated with information sharing (Scholz et al., 2017) and with health-related behavior change (Falk & Bassett, 2017; Whelan et al., 2017).

The empathy network and vmPFC and health information. There are good reasons to suppose that the psychological profiles of the Empathy Network and vmPFC may relate to the psychology of information behavior. First, information sharing is a social and personally meaningful activity, involving social cognition and hence the Empathy Network (Veinot, 2010; Wolf & Veinot, 2015), thus likely involving the vmPFC (Falk & Bassett, 2017; Tompson, Lieberman, & Falk, 2015). To illustrate these points, people are more likely to share information with others for whom they feel a sense of

DOI: 10.1002/asi

empathic concern, and information sharing fosters positive emotions (Jones, Veinot, Pressler, Coleman-Burns, et al., 2017; Veinot, 2010). Second, with regard to information use, individuals who feel socially supported and affirmed in their personal values corresponds to activation of the Empathy Network, which, in turn, facilitates the modification of behavior (Cascio et al., 2016; Crocker, Niiya, & Mischkowski, 2008). Moreover, increased activation of the Empathy Network and vmPFC during the reception of health information may facilitate effective use of that health information (for instance, Falk & Bassett, 2017). These psychological processes contribute to information and self-management behaviors (Tompson et al., 2015), including the tendency to share information (Falk, Morelli, Welborn, Dambacher, & Lieberman, 2013).

The analytic network. The Analytic Network is comprised of lateral parietal and lateral prefrontal cortices (Duncan & Owen, 2000; Shulman et al., 1997; Figure 1). These regions have also been referred to as the Task Positive Network (TPN), and overlap both the Dorsal Attention Network and the Fronto-Parietal Control Network (which are adjacent to and highly interconnected with each other). For reasons outlined elsewhere, we reject the alternative labels as misleading and refer to these regions as the Analytic Network (Friedman & Jack, 2018; Jack et al., 2013; Jack, Dawson, & Norr, 2013; Boyatzis et al., 2014; Friedman et al., 2015; Jack et al., 2016). The Analytic Network is activated by nonsocial reasoning, executive function, and inhibitory control (for instance, overriding impulses), as well as logical, mathematical and scientific reasoning (Corbetta et al., 1998; Duncan & Owen, 2000; Goel, 2007; Jack, Dawson, Begany, et al., 2013). This network is commonly called the TPN (Fox et al., 2005) and is implicated in the comprehension and use of fact focused information, as well as health behavior change (Berkman & Falk, 2013; Whelan et al., 2017).

There are important reasons why the psychological functions served by the Analytic Network are also highly relevant to health information behavior. First, these psychological processes help individuals devise task-oriented plans related to their health (for instance, counting/tracking calories and sodium), understand the cause–effect relationships of their behaviors and their health, and comprehend often-complex biological explanation, or planning and executing a search for information. Understanding information is a prerequisite for effectively using and sharing it. Moreover, because the Analytic Network is unrelated to social cognitive processes (Jack, Dawson, Begany, et al., 2013; Van Overwalle, 2010), it may be more relevant for (nonsocial) information seeking and information use—as opposed to the more social aspect of information sharing.

Relationship between analytic and default mode networks. We were motivated to simultaneously assess activity in the DMN (Empathy Network & vmPFC) and the Analytic Network because they share an antagonistic or anticorrelated relationship (Bressler & Menon, 2010; Fox et al., 2005; Uddin, Clare Kelly, Biswal, Xavier Castellanos, & Milham, 2009). That is, as one network becomes more active, the other becomes less active and vice versa (Meyer, Spunt, Berkman, Taylor, & Lieberman, 2012). For example, emotionally engaging tasks activate the Empathy Network and simultaneously deactivate the Analytic Network; in contrast, scientific reasoning tasks activate the Analytic Network and simultaneously deactivate the Empathy Network (Jack, Dawson, Begany, et al., 2013). However, these networks also have an antagonistic relationship in the absence of any task, when individuals are at rest and engaged in spontaneous cognition (Fox et al., 2005). Higher anticorrelation between these networks is associated with higher IQ, better mental health, and better task performance (Anticevic et al., 2012; Buckner, Andrews-Hanna, & Schacter, 2008; Whitfield-Gabrieli & Ford, 2012).

To date, we are not aware of any studies that simultaneously measure and compare the function of both networks in order to investigate how the distinct types of neural processing of health information relate to health information seeking, sharing, and use behaviors. However, given that both networks appear relevant to health information processing, evidence suggests that comparing measures from both brain networks will be informative about the key drivers of health information behavior. In the present study we investigated patterns of neural activation in relation to self-reported health information behaviors, with a focus on the tendency for neural differentiation between one type of health information that generally engages the network in question, and another type of health information that generally disengages that region.

Method

This investigation was a substudy utilizing baseline data from the Mindfulness Attitude to Deliver Dietary Approaches to Stop Hypertension (MAD-DASH) study, a randomized controlled, 9-month trial investigating the effects of a mindfulness intervention to improve blood pressure and self-management behaviors in African Americans with prehypertension. We used a descriptive, cross-sectional design to explore associations between baseline functional magnetic resonance imaging (fMRI) neural activation and information behavior survey data. Institutional Review Board approval was obtained prior to conducting this work.

Participants

Participants in this study were African Americans with modestly elevated blood pressure. We focused on African Americans given the well-established public health burden of hypertension in this community, and thus the importance of supporting self-management-related information behaviors in this group. Participants were primarily

DOI: 10.1002/asi

recruited using bus advertisements in Cleveland, Ohio. Eligible participants (in the parent trial): (a) self-identified as African American/Black, (b) were 21+ years of age, (c) had resting systolic blood pressure (SBP) 120–139 and/or diastolic blood pressure (DBP) 80–89 mmHg per the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure JNC-8 criteria for prehypertension (James et al., 2014), or (d) had resting SBP >140, but had never been diagnosed with hypertension. Individuals were excluded if they: (a) were diagnosed with hypertension or taking antihypertensive medication, (b) used glucocorticoids (within 6 months), (c) had adrenal insufficiency, (d) planned to move during the next 9 months, (e) scored <20 on the Montreal Cognitive Assessment, (f) received counseling (3+ times/week), or (g) practiced yoga/meditation. Participants who could not undergo fMRI were excluded—those having heart pacemakers or defibrillators, metal anywhere in their body, implanted devices, or those who were pregnant. Of those who were assessed for eligibility, 66% were unable to enroll in the study (62% did not meet inclusion criteria; 4% refused). Candidates who did not meet criteria for inclusion were thanked for their time and provided with a $10 incentive.

The sample consisted of 19 participants: 53% women, 53% attended or completed college or technical training, 58% had monthly incomes between $600–$999, and 63% were single. The mean age of the sample was 52.47 years (SD = 14.02), with ages ranging from 24–76 years. Participants' mean SBP was 134.17 mmHg (SD = 13.15) and mean DBP was 81.26 mmHg (SD = 4.32).

Procedures

Individuals interested in participating were invited to the Clinical Research Unit for screening. Potential participants completed the Montreal Cognitive Assessment, a screening assessment used to identify cognitive impairment (Nasreddine et al., 2005) and had their blood pressure measured. A trained research nurse measured each participant's blood pressure using an automated sphygmomanometer after 10 minutes of sitting with feet flat on the floor (Chobanian et al., 2003). Three measurements were taken and averaged. Participants with excessively elevated blood pressures were encouraged to follow up with their healthcare provider. Individuals with blood pressure levels that did not meet inclusion criteria (n = 6), were not enrolled in the study and provided with a $10 incentive for participating in screening.

Eligible participants completed two visits. During the first visit, health information behavior was assessed (surveys, see Information Behavior Measures, below). Participants received $30 incentive for completing the first visit. Participants who returned for a second visit to undergo fMRI received an additional $20 incentive.

fMRI Protocol

We designed a paradigm to examine brain activity while participants attended to distinct types of health information. There were two conditions of relevance to the current investigation, each of which consisted of carefully selected video clips (with sound) downloaded from the Internet. The videos were selected based on the following categories:

Fact focused (FF). Animations depicting anatomy and physiological processes of health and disease (for instance, mechanisms underlying heart function, insulin sensitivity, and how HIV affects the immune system).

Coping stories (CS). Affected individuals or their family members describing emotionally salient aspects associated with overcoming and managing their chronic illness (for instance, individuals recalling the success of beating cancer, having a heart attack, their memory of contracting HIV).

Activation

These content categories were selected, by hypothesis, to elicit unique patterns of activation and deactivation in the Analytic Network vs. the Empathy Network and vmPFC—which were modeled directly on previous paradigms.[1] The FF condition was expected to activate the Analytic Network and deactivate both the Empathy Network and vmPFC, whereas the CS condition was expected to activate both the Empathy Network and vmPFC and deactivate the Analytic Network.

Differential activation (differentiation). We focused on three prespecified measures of theoretical interest. Differential activation in the Analytic Network (activity for FF condition minus activity for CS condition) was used because it was hypothesized it would index analytic processing of health information. Differential activation in the Empathy Network (activity for CS condition minus activity for FF condition) was used because it was hypothesized this would index empathic processing of health information. Differential activation in the vmPFC (activity for CS condition minus activity for FF condition) was used because it was hypothesized this would index strength of processing associated with a sense of affective meaning in response to health information.

A priori regions of interest. Three a priori regions of interest were identified from previously conducted studies.[2]

[1] True activations and deactivations – true in the sense that they activate and deactivate relative to a resting baseline – would necessitate that Empathy Network regions were always above .00001% signal change for the coping stories conditions and always below -.00001% for the Fact focused stories (and vice versa for Analytic Network regions). However, this is not always the case.

[2] Network regions. The Empathy Network regions, in Taliarch space, include 0, 45, 26 (39 voxels) and –2, –55, 31 (139 voxels). The Analytic Network regions include –39, 32, 20 (20 voxels), –39, –48, 42 (36 voxels) and –52, –39. 42 (28 voxels).

DOI: 10.1002/asi

Two regions of the Empathy Network and three regions of the Analytic Network were derived from prior imaging data (Jack, Dawson, Begany, et al., 2013), which identified the core parts of the two networks demonstrating the greatest task differentiation. The Analytic Network regions correspond to those voxels (the 3D pixels that comprise the smallest spatial unit of data) that met the highest statistical threshold (random effects strict cognitive conjunction)[3] as being reliably activated during analytic processing and deactivated during empathic processing. Empathy Network regions were defined in the same way except it was activated during empathic processing and deactivated during analytic processing. Both of these regions comprised voxels taken from two distinct parts of the Analytic and Empathy Networks. The signal from each of these a priori regions was averaged together within networks, meaning that the three Analytic Network regions constitute a single "analytic measure" and the two Empathy Network regions constitute a single "empathic measure" (see Analysis, below).

The third region of interest, the vmPFC, was identified based on its key role in behavior change and information sharing (Falk et al., 2011; Falk, Berkman, Mann, Harrison, & Lieberman, 2010; Falk, O'Donnell, & Lieberman, 2012; Vezich, Falk, & Lieberman, 2015; Whelan et al., 2017). By contrasting these conditions (CS minus FF), we identified a whole brain-corrected statistically significant group of face-connected voxels.[4] This region of peak differentiation between FF and CS conditions overlapped regions identified in the prior cited studies.

fMRI Materials and Methods

MRI acquisition. Imaging data were acquired with a Siemens 3T Skyra scanner at the Case Center for Imaging Research. Participants first underwent a T1-weighted magnetization-prepared rapid-acquisition gradient-echo structural sequence (MP-RAGE), followed by four T2*-weighted functional task runs (230 volumes each). Functional runs used an echoplanar imaging (EPI) sequence with 36 contiguous slices 3.5 mm slices, 3.5 X 3.5 mm in-plane resolution, echo time (TE) = 20 ms, flip angle = 90°, repetition time (TR) = 2.00 sec. Stimuli were presented using Eprime software, version 2.0.10 (Sharpsburg, PA). Videos were projected onto a screen attached to the MRI head coil using an Avotech projector and were viewed by subjects through a mirror. Sound was presented through integrated Avotech headphones. An integrated microphone allowed for two-way communication.

Scanner paradigm. Each of the four functional runs lasted 7 minutes and 40 seconds (230 volumes). Over the entire scanning session of four runs, there were 16 videos per condition. Each video was downloaded from open-source channels on Youtube.com. We edited in Microsoft Movie Maker (Redmond, WA) to be exactly 23,000 ms in length. Interspersed between the videos was a "rest" condition where participants passively viewed a picture of a red fixation cross on a black background. The rest condition was equal in frequency and length to the three video conditions (23 sec). Variable fixation periods (jitters) were displayed for 1–5 seconds after each video (as well as after the rest periods). The length of jitters between conditions, and the order of the three experimental conditions and resting control condition, were pseudorandomized in MatLab (MathWorks, Natick, MA) prior to designing the study in Eprime. Each participant was presented with the same conditions, in the same order and temporal spacing. A fixed sequence design was used because the primary goal was to compare patterns of brain activity between participants. To promote careful attention, participants were instructed that they would be quizzed about the videos after the fMRI scan. No responses were required during the scan.

Information Behavior Measures

Health information behavior was measured using the Modes of Health Information Acquisition, Sharing, and Use Scale (Meadowbrooke et al., 2014; Veinot et al., 2013). This 21-item self-report survey has three subscales (see Appendix). The scales measure how often the participant seeks (eight items, Cronbach's α = .7), shares (five items, Cronbach's α = .7), and uses (eight items, Cronbach's α = -.9) information about blood pressure to make self-management decisions. On a Likert-type scale, items range from 1 *(never)* to 5 *(very often)*. Scores are calculated by summing the items, with higher scores indicating greater frequency of engaging in a particular information behavior.

Analysis

Before the statistical analyses were conducted, all imaging data were preprocessed, using the Washingtion University in St. Louis program, *fidl.* First-level analyses were also carried out using *fidl.* A General Linear Model (GLM) with assumed Hemodynamic Response Functions (HRF) was used to estimate the average magnitude of each participant's response to both video conditions. GLM encompasses the family of linear statistical analyses that are the workhouse of fMRI (Friston et al., 1994; Whelan et al., 2017). Baseline and linear trends were estimated alongside the assumed HRF associated with the video conditions. The rest condition was not explicitly modeled, and so was implicitly captured by the baseline estimate. The HRF we used for modeling the video conditions is similar to that used by a variety of common neuroimaging analysis programs and is based on careful work modeling the HRF to visual stimuli in V1 (Boynton, Engel, Glover, & Heeger, 1996). Voxel-based first-level estimates of response magnitude were then entered into a second-level analysis to allow random effects analysis of effects attributable to the

[3] Strict cognitive conjunction is the most statistically valid way to make inferences about brain regions which behave similarly, across different contrasts.

[4] Face connected voxels are those which are connected to each other by at least one face, or side of their 3d cube.

DOI: 10.1002/asi

TABLE 1. Means, standard deviations, and ranges of study variables ($n = 19$).

	Mean *(SD)*	Range
Information seeking	18.21 (4.59)	8–25
Information sharing	9.84 (2.97)	5–14
Information use	21.37 (7.72)	8–34
Empathy network (CS-FF)	0.24 (0.23)	−0.10–0.84
vmPFC (CS-FF)	0.08 (0.33)	−0.80–0.53
Analytic network (FF-CS)	0.09 (0.28)	−0.47–0.60

Note. CS = coping stories; FF = fact focused; Values reflect % change in BOLD response in prespecified regions between the two different experimental conditions (see Methods). The percent change is a normalized beta value.

population. We averaged values over voxels in the prespecified regions for the FF and CS conditions. These were extracted from the GLM as average estimates and were then entered in a separate analysis program with the behavioral measures.

We summarized all study variables using descriptive statistics: range, frequencies, and percentages. Statistical analyses were conducted with Stata version 14 (StataCorp, 2015). Because the distributions of the Analytic and Empathy Network variables were skewed, Spearman rho correlations were used to examine the relationships among the variables. All tests were two-sided. Because this study was an exploratory and hypothesis-generating (similar to a phase II trial), a significance level of .10 was used for all hypothesis tests (Rubinstein et al., 2005). Consistent with the American Statistical Association statement on p-value, we emphasized the magnitude of the effect sizes, nonzero correlation coefficient, and its clinical relevance (Wasserstein & Lazar, 2016). Thus, all reported findings were interpreted using traditional effect size conventions (d: small = .20, medium = .50, large = .80; ρ: small = .10, medium = .30, large = .50) to characterize findings (Cohen, 1992; Ferguson, 2009).

Results

Health Information Behavior Measures

Information seeking. The mean score (Table 1) reflects that participants were moderately engaged in seeking information about self-management of blood pressure, with 52.6% of participants reporting that they sometimes or often looked for information about blood pressure self-management. With regard to nonpurposeful information seeking, participants reported that sometimes, often, very often they learned unexpected things about high blood pressure from a media source (63.2%) or when they talked with others (73.8%). Participants were less likely to seek information with others (36.8% stated that they never did) or go places they would learn things about blood pressure self-management (47.4% stated they never did).

Information sharing. The mean score (Table 1) reflects that participants were moderately engaged in sharing information with others on how to lower their blood pressure levels. More than half of the participants sometimes, often, or very often (52.6%) told others information they knew about high blood pressure and gave advice or encouraged others about blood pressure management or prevention (57.9%). The majority reported that they never emailed others blood pressure information (63.2%), nor did they organize events to discuss high blood pressure (78.9%).

Information use. The mean scores on this measure (Table 1) showed that participants were highly engaged in using information to make decisions about how to self-manage their blood pressure. About half of the participants reported that they sometimes or often used information to evaluate their risk of hypertension (63.2%). In addition, participants sometimes, often, or very often used information to better understand their condition (73.7%), make decisions about how to treat their elevated blood pressure (57.9%), or to decide when to see a healthcare professional (47.4%). Most (63.2%) reported that they never used information to track or monitor their blood pressure at home.

Associations. As expected, there were large, positive correlations among the information behaviors: seeking and sharing ($\rho = .62$, $p < .01$), seeking and use ($\rho = .77$, $p < .01$), and sharing and use ($\rho = .78$, $p < .01$). As expected, differentiation in the Empathy Network (CS minus FF) and vmPFC (CS minus FF) demonstrated a large positive correlation ($\rho = .88$, $p < .01$). Both of these results reflected the contrast of the FF condition minus the CS condition (positive when averaged across all participants). There was no correlation between differentiation in the Analytic Network (FF minus CS) and differentiation in the vmPFC ($\rho = -.15$, $p = .54$), nor was there an association between differentiation in the Analytic and Empathy Networks ($\rho = -.18$, $p = .47$).

Health Information Behavior and Neural Measures

Our goal was to examine relationships between measures of health information behavior and neural measures of health information processing. As shown in Table 2, there was a large, positive correlation between information sharing and both vmPFC differentiation and Empathy Network differentiation. In contrast, Analytic Network differentiation was unrelated to information sharing. Information

DOI: 10.1002/asi

TABLE 2. Associations (Spearman correlation coefficients) among health information behaviors and neural processing (n = 19).

	Neural processing		
	Empathy Network (CS minus FF)	vmPFC (CS minus FF)	Analytic Network (FF minus CS)
	ρ (p-value)	ρ (p-value)	ρ (p-value)
Information seeking	.13 (.60)	.02 (.93)	−.05 (.85)
Information sharing	**.43 (.06)**	**.53 (.02)**	−.24 (.32)
Information use	.20 (.41)	.23 (.35)	−.07 (.76)

Note. Cohen's (1992) effect size conventions for ρ: small = .10, medium = .30, large = .50; CS = coping stories; FF = fact focused.

seeking and information use were not associated with any of the neural measures (Table 2).[5]

Two indices of neural activation in relation to information sharing (vmPFC & Empathy Network) were significantly different from zero ($p < .10$) and approached conventions for large effect sizes. Correlations between information use and neural indices were not statistically significant, but the magnitude of the correlations with vmPFC and Empathy Network approached conventions for medium effect sizes. Finally, no statistically significant relationships with the Analytic Network were found, but the strength of the association with information sharing was negative and approached conventions for a medium effect size.

Given the pattern of our findings, we elected to conduct an exploratory post-hoc test of dependent correlations (Steiger, 1980) to examine whether the magnitude of the correlations between neural indices was stronger in relation to information sharing as compared with information seeking and information use. Accordingly, vmPFC was more strongly associated with information sharing as compared with information seeking (z = 3.03, $p < .001$, Cohen's d = 1.39) and information use (z = 2.25, $p < .03$, Cohen's d = 1.03). Similarly, the Empathy Network was more strongly associated with information sharing as compared with information seeking (z = 2.48, $p < .01$, Cohen's d = 1.13) and information use (z = 1.99, $p < .03$, Cohen's d = 0.91). Finally, the Analytic Network was more strongly associated in a negative direction with information sharing as compared with information seeking (z = 1.58, $p < .06$, Cohen's d = 0.72) and information use (z = 1.45, $p < .08$, Cohen's d = 0.66).

Discussion and Conclusion

This study was the first to examine the relationships among self-reported information behavior and neural measures of health information processing in a sample of African Americans with prehypertension. Specifically, we investigated how differentiation in two antagonistic neural networks (Analytic and Empathy Networks) were related to self-reported use, seeking, and sharing of information related to blood pressure. We found that information sharing was positively associated with differentiation in a priori identified regions, corresponding to the Empathy Network and vmPFC. Increased activation during the reception of health information that focuses on a social and emotional narrative, and greater deactivation of the Analytic Network during the reception of factual health information, was related to increased information sharing. That differentiation of these regions was related to greater self-reported information sharing is consistent with prior work on information sharing and behavior change (Tompson et al., 2015). This was the first study to show that differentiation between regions of the Analytic and Empathy Networks was related to information sharing.

Information Sharing and DMN Task Differentiation

Previous research has shown that the vmPFC is associated with valuation and sharing of information, emotional and parasympathetic regulation, and self-affirmation (Bartra et al., 2013; Eisenberger & Cole, 2012; Roy et al., 2012). The Empathy Network is associated with representing one's own and other's thoughts and feelings (Denny et al., 2012), expressing concern for others, prosocial support, and empathizing with others (Jack, Dawson, Begany, et al., 2013; Jack, Dawson, & Norr, 2013; Rameson et al., 2012). It is notable that the regions that best predict information sharing are actually suppressed when individuals are engaged in the analytic processing necessary to grasp relevant content. Of course, analytic comprehension is necessary for understanding information, but the current results show a more important role for social and emotional processing associated with the Empathy Network in the sharing of health information. These findings are consistent with prior neuroimaging work demonstrating that these social and emotion processing regions (for instance, Empathy Network and vmPFC) are associated with persuasion and motivation to share information (Falk & Bassett, 2017; Tompson et al., 2015; Whelan et al., 2017).

The current study adds to the growing body of work highlighting the importance of engaging these psychological processes when developing healthcare information. Engagement and disengagement of the vmPFC is inferred from stronger differentiation, which was defined by increased activation in response to the CS

[5] As a secondary analysis, we examined relationships among gender, health information behavior, and neural measures; we did not identify significant difference by gender.

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videos and decreased activation in response to the FF videos. Our finding that information sharing was associated with social and emotion processing may also explain previous findings that participants who shared information, in an attempt to help others, were more likely to use information to make self-management decisions (Jones, Veinot, & Pressler, 2017).

This is the first study to demonstrate that this neural signature (i.e., increased differentiation in the vmPFC and Empathy Network) is associated with self-reported information sharing behaviors in any group; in this case, African Americans with elevated blood pressures. Given that health information is commonly conveyed as detached and analytic in nature, our findings highlight the importance that processing of socially and emotionally salient health information is more closely associated with health information sharing. One implication of our findings is that interventions that reliably disseminate health information may be more efficacious when information is conveyed by analytic *and* socio-emotional means, so that neural regions associated with goal-setting and evaluating social and personal relevance are engaged.

Information Seeking and Use

Information seeking and information use were not related to the measures of neural processing. This stands in contrast to prior information science research suggesting activation of different parts of the brain during specific tasks associated with information searching, including using search engines, reviewing search results, and selecting them for relevance (Mostafa et al., 2015; Mostafa & Gwizdka, 2016; Small, Moody, Siddarth, & Bookheimer, 2009). The absence of any significant or trending correlations may be due to the measures used and the small sample size in this study, or the fact that we did not directly observe information seeking, sharing, and use during the fMRI. Before saying that these variables are not correlated, studies should be conducted with larger samples, while directly observing these behaviors. Nevertheless, this work demonstrates the feasibility of conducting information science research using neuroprocessing methods, while extending such research beyond its current focus on information search to include the related field of information behavior (O'Brien, Dickinson, & Askin, 2017).

Participation in Information Behavior

Although the participants were not diagnosed with hypertension, survey results indicated that they were still seeking and sharing blood pressure information, and using it to make blood pressure self-management decisions. This finding is similar to other studies reporting participants who were not clinically diagnosed with hypertension were still actively engaging in related health information behavior (Jones, Wright, et al., 2017). This suggests that interventions focused on participation in health information and self-management behaviors may appeal to individuals with prehypertension, since they already engage in these behaviors without prior encouragement. Our findings point to the importance of developing interventions that include a social narrative, in addition to analytic information. This extends prior work implicating the role of the Empathy Network in information and self-management behaviors (Falk & Bassett, 2017; Tompson et al., 2015).

Limitations

As with all studies, the findings we reported must be interpreted within the context of the study. One limitation was the small sample size of 19 participants. Despite this small sample, we were able to identify statistically significant findings that correspond well to prior literature. Now that we have successfully established feasibility, we can replicate this study in larger samples and continue to examine these relationships. Another limitation is that our fMRI protocol was newly developed and this was the first time that it was tested. However, the development was guided by prior theory and previous neuroimaging studies (Jack, Dawson, Begany, et al., 2013; Jack, Dawson, & Norr, 2013) that have achieved patterns of neural activity very similar to those produced here. Given these possible limitations, this novel study was an opportunity to explore information behaviors and neuroprocessing in an at-risk African American sample. Our findings further contribute to our understanding of the neurological mechanisms underlying information behavior and self-management in general, and in a vulnerable population that has an increased risk for negative cardiovascular outcomes.

Conclusion

Although health information behavior is closely related to participation in self-management behavior, to our knowledge this is one of the first studies to investigate health information indices in relation to theoretically motivated patterns of neural activity. In particular, we examined the degree to which individuals were able to differentially activate the Empathy Network, vmPFC, or Analytic Network as a function of information that was selected to be factual vs. social and emotional in content. We then examined these patterns in relation to behavioral measures of health information sharing. Our findings show that stronger differentiation in the Empathy Network and vmPFC was associated with greater self-reported information sharing—a practice elsewhere shown to be associated with blood pressure self-management. Our findings have the potential to inform theory and assist scientists and clinicians to develop interventions that are specific and effective. In particular, our findings indicate how important it is to construct health messages that are socially and emotionally engaging. These results are applicable to African Americans with prehypertension, an important population to target because of the high prevalence of hypertension. Thus,

DOI: 10.1002/asi

our findings have the potential to improve understanding of health information behavior and how it relates to behavior changes.

Appendix

Appendix Measure

Modes of Health Information Acquisition, Sharing, and Use

Because your blood pressure has been higher than normal, you may have received information about high blood pressure. We would like to know more about how you usually get this information. Please tell us how much you have gotten information in each of the following ways in the past 12 months.

1. I look for information about high blood pressure by myself.

2. I look for information about high blood pressure with someone else.

3. People give me information about high blood pressure without me asking for it.

4. I accidentally find information about high blood pressure while I look for information on other topics.

5. I learn unexpected things about high blood pressure from the media (when I watch television, listen to the radio, or read the newspaper).

6. I learn unexpected things about high blood pressure when I talk to other people.

7. I ask someone else to look for high blood pressure information for me.

8. I go to places where I think I will learn new things about hypertension (for instance, events, public lectures, or workshops).

Sometimes when people receive information, they share it with others. We would like to know more about how you have shared information about high blood pressure. Please tell us how much you shared information in each of the following ways in the past 12 months.

9. I give documents, Internet links, or emails to other people.

10. I tell people things I know about high blood pressure.

11. I give people advice or encouragement about high blood pressure prevention or treatment.

12. I organize events in which high blood pressure is discussed.

13. I recommend doctors or other health professionals to people with high blood pressure, or to people who think they might have it.

With your blood pressure being slightly elevated (pre-hypertension), you may have started using information that you have received. Please tell us how much you have used information about high blood pressure in each of the following ways in the past 12 months.

14. Evaluate your risk for high blood pressure.

15. Decide whether to see a doctor, nurse, or other healthcare professional.

16. Monitor and track your blood pressure at home.

17. Understand your blood pressure readings or other test results.

18. Decide how to treat high blood pressure.

19. Plan or make high blood pressure-friendly meals.

20. Change your overall approach to maintaining your health.

21. Ask a healthcare professional questions or get a second opinion from another provider.

Responses: Never, Rarely, Sometimes, Often, Very Often.

Acknowledgments

Research reported in this article was supported by the National Institute of Nursing Research of the National Institutes of Health under Award Numbers P30NR015326 and P30NR015326-02S1 and the Clinical and Translational Science Collaborative of Cleveland, KL2TR000440, from the National Center for Advancing Translational Sciences (NCATS) component of the National Institutes of Health and NIH Roadmap for Medical Research. Dr. Fresco was supported by National Heart, Lung, and Blood Institute grant 1R01HL119977. The neuroimaging work made use of the High Performance Computing Resource in the Core Facility for Advanced Research Computing at Case Western Reserve University.

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