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Older age and online health information search behaviors: The mediating influence of executive functions

Victoria M. Kordovski[a], Savanna M. Tierney[a], Samina Rahman[a], Luis D. Medina[a], Michelle A. Babicz[a], Hanako Yoshida[a], Erin M. Holcomb[b], Clint Cushman[c] and Steven Paul Woods[a]

[a]Department of Psychology, University of Houston, Houston, TX, USA; [b]Houston Neuropsychology Associates, Houston, TX, USA; [c]Department of Psychiatry, University of California, San Diego, CA, USA

ABSTRACT

Introduction: Searching the internet for health-related information is a complex and dynamic goal-oriented process that ostensibly places demands on executive functions, which are higher-order cognitive abilities that can deteriorate with older age. This study examined the effects of older age on electronic health (eHealth) search behavior and the potential mediating influence of executive functions.
Method: Fifty younger adults (≤ 35 years) and 41 older adults (≥50 years) completed naturalistic eHealth search tasks involving fact-finding (Fact Search) and symptom determination (Symptom Search), a neurocognitive battery, and a series of self-report questionnaires.
Results: Multiple regression models controlling for potentially confounding psychiatric symptoms, health conditions, literacy, and demographic variables revealed that older adults were slower and less accurate than younger adults on the eHealth Fact Search task, but not on the eHealth Symptom Search task. Executive functions mediated the relationship between age and Fact and Symptom Search accuracy, independent of basic processing speed and attention. Parallel mediation models showed that episodic memory was not an independent mediator of age and search accuracy for either eHealth task once speed/attention and executive functions were included.
Conclusions: Older adults can experience difficulty searching the internet for some health-related information, which is at least partly attributable to executive dysfunction. Future studies are needed to determine the benefits of training in the organizational and strategic aspects of internet search for older adults and whether these findings are applicable to clinical populations with executive dysfunction.

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electronic health literacy; ecological validity; verbal fluency; abstraction; set-shifting

Over the past three decades, the internet has emerged as a major source of health-related information and an estimated 60–65% of Americans use the internet for this purpose (Perrin, 2015). Health-related topics constitute about 5–10% of all searches on the internet (e.g., Eysenbach & Kohler, 2003), which increased in both frequency and public health relevance during the COVID-19 pandemic (GoogleTrends, 2020). People commonly consult internet sources when they experience new health symptoms, are newly diagnosed with a health condition, are prescribed a new treatment, or are managing an ongoing health condition (e.g., Fox & Rainie, 2002). Information from electronic health (eHealth) sources is commonly rated as equal to (or better than) the information obtained from healthcare providers (Diaz et al., 2002) and is given weight in making health-related decisions (Fox & Rainie, 2002). However, eHealth information is largely unregulated (Skierkowski et al., 2019) and misinformation is commonly encountered (e.g., Krause et al., 2020). Therefore, it is important to specify the factors (e.g., cognitive, behavioral, and systemic) that underlie accurate and effective use of the internet for health-related purposes.

eHealth information seekers tend to be younger White women who have higher socioeconomic status, poorer health, and more internet experience (Bundorf et al., 2006; Diaz et al., 2002; Houston & Allison, 2002; Rice, 2006). However, older adults are among the fastest-growing groups of internet users (Perrin, 2015). Given the increased prevalence of health problems among older adults (Buttorff et al., 2017), it is not surprising that internet searches for health-related information are common in this demographic (Van Deursen & Helsper, 2015). Indeed, many older adults report that the internet is helpful in making health-related decisions (Tennant et al., 2015). Yet older adults can experience difficulties navigating the internet to search for health-related information (e.g., Ebner et al., 2020). Older adults tend to develop inefficient search plans (Chevalier et al., 2015), use less effective search

CONTACT Steven Paul Woods spwoods@uh.edu Department of Psychology, University of Houston, 126 Heyne Building (Ste. 239d), Houston, TX, USA

strategies (Dommes et al., 2011), have more difficulty disengaging from unsuccessful strategies (Chin & Fu, 2010), and switch less frequently between websites (Chevalier et al., 2015).

Conceptual models on the neurocognitive processes involved in information search and utilization on the internet can inform the apparent age-related differences in eHealth search (Hearst, 2009). Standard information-search models involve steps to: identify the goal or problem, express the information in the search system (i.e., a generative query), evaluate the results, and reiterate the process until the goal has been achieved (e.g., Marchionini & White, 2007). Other models view information-seeking as occurring in discrete stages (e.g., Kuhlthau, 1991), as dynamic (e.g., Bates, 1989), or as a guided by strategies (e.g., Bates, 1979). Cognitive adaptations of the information search models view information-seeking as representative of how people generally operate in the world: Individuals have an idea of their desired goal and use their cognitive understanding of system input and output to guide their behaviors. Thus, these goal-directed eHealth behaviors may be viewed through the lens of executive functions, which is an umbrella term for a group of neurocognitive abilities involved in cognitive and behavioral regulation (e.g., Miyake & Friedman, 2012; Norman, 1988). In the neuropsychological literature, some models of executive functions are organized in a problem-solving framework, parallel to those in the information search literature. For example, Zelazo et al. (1997) view executive functions as a macro-construct that spans four stages of problem-solving: problem representation, planning (the selection of actions of a sequence), execution (of the steps), and evaluation (of behavior and subsequent monitoring). Moreover, the execution of these higher-order processes requires coordination of the core executive control systems: inhibitory control, working memory, and cognitive flexibility (Miyake et al., 2000). In this way, the search process is conceptualized as an executive process. At face value, eHealth search behaviors rely heavily on several core executive functions, including goal setting and planning, generativity (e.g., generating relevant key search terms), cognitive flexibility (e.g., shifting in between websites), and novel problem-solving and decision-making. Neuroimaging research shows that the prefrontal cortex, which supports executive functions, plays a key role in internet search behaviors in healthy adults (e.g., Dong & Potenza, 2015, 2016; Small et al., 2009)

As such, it is reasonable to posit that executive functions may contribute to older adults' difficulties navigating the internet for health-related information, particularly when that information is complex. The brain networks that support executive functions (e.g., prefrontal cortex) are susceptible to the effects of aging (e.g., Turner & Spreng, 2012, Hedden & Gabrieli, 2004), which can have downstream consequences on health-related activities of daily living in older adults (e.g., McAlister & Schmitter-Edgecombe, 2016). In a recent systematic review, Woods et al. (2019) found that executive functions showed medium associations with performance on internet search tasks among healthy adults across the lifespan (e.g., Agree et al., 2015; Austin et al., 2017; cf. Kordovski et al., 2020), including the subdomains of rapid set-shifting (e.g., Dommes et al., 2011; Sharit et al., 2015) and abstraction (e.g., Czaja et al., 2010; Sharit et al., 2008). Presumably, executive functions partly explain the relationship between older age and internet search performance (Czaja et al., 2001). For example, Sharit et al. (2008) reported that the effects of older age on both simple and complex internet search tasks were dampened when measures of reasoning and working memory were included. Similarly, Chevalier et al. (2015) reported that the effects of older age on an internet search task disappeared once the models were adjusted for cognitive flexibility, vocabulary, and search strategies. However, no studies have directly examined whether executive functions mediate the relationship between older age and eHealth search behaviors, which has added personal and public health relevance, given the importance of the internet as a health tool during the COVID-19 pandemic.

Of course, there is variability in the complexity of eHealth search activities, which might range from relatively straightforward, fact-based searches (e.g., What was the name of that medication for migraines?) to more complex, nuanced searches that require greater levels of health literacy and discernment (e.g., Why am I having problems with my sense of smell?). Age-related difficulties in internet search behaviors may be exacerbated by greater task demands (e.g., Chevalier et al., 2015). For example, Sharit et al. (2008) asked older and younger adults to complete a series of online medical, health, and wellness-related questions that varied in task demands. Older adults performed more poorly than the younger adults on the complex search problems (e.g., find three types of people who should not get a flu shot) but did not differ on the simpler problems (e.g., find a specific government website).

The current study examined whether older age was associated with poorer performance on two measures of health-related internet search behavior that differ in search complexity (see Kordovski et al., 2020). In the more structured, simpler eHealth Fact Search task, participants asked to use the internet to answer five questions about migraines. In the less structured, thus more complex, eHealth Symptom Search task, participants were asked to search the internet for a plausible diagnosis given a set of symptoms from a fictional vignette. It was hypothesized that older adults would take longer than younger adults to complete both health-related search tasks. We also expected that the effects of older age on health-related search accuracy would be dampened for the more structured fact-based task than the less structured symptom-based task. Finally, we examined whether executive functions might mediate part of the potential aging effect on the less structured eHealth Symptom Search task. The specificity of the hypothesized mediating effects of executive functions was examined: 1) in parallel mediation models that included lower-order cognitive components (i.e., speed and attention); and 2) in separate analyses examining the mediating effects of episodic memory, which is a higher-order neurocognitive function that is also affected by aging (e.g., Spencer & Raz, 1995) and is associated with eHealth behaviors (e.g., Woods et al., 2019).

Method

Participants

A total of 52 younger adults and 45 older adults were recruited for this study. The younger adults (18–35 years) were recruited through the University of Houston (UH) experiment management system for students enrolled in psychology classes or from the community via word of mouth. The older adults (50–82 years) were recruited via both in-person (e.g., fliers in local medical clinics, libraries, and community centers) and online (e.g., postings on Facebook, Nextdoor, and Craigslist) community outreach methods. We included adults aged 50 and older because: 1) there is emerging recognition that cognitive and brain aging begins in midlife (Elliott et al., 2019; Lindenberger, 2014); 2) there are many funding initiatives that identify middle age as an incubation phase for incident neurocognitive disorders in later life (e.g., Ritchie et al., 2015); and 3) cognitive aging efforts in chronic disease populations are increasingly focused on middle-age in the context of both accelerated and accentuated aging (Stoff, 2004). Inclusion criteria were adequate proficiency in English, at least 1.5 hours per week of internet use, and capacity to provide informed consent. The internet use hour requirement was based on data showing that older adults who use the internet even minimally report doing so for at least 1.6 hours per week (Choi & DiNitto, 2013). Although performance validity failures in non-clinical research studies are low (Woods et al., 2003), we included all participants who obtained scores of ≥6 on Reliable Digit Span (Schroeder et al., 2012). We excluded persons with major neurological disorders (e.g., traumatic brain injury, seizure disorders, multiple sclerosis), severe psychiatric conditions (e.g., bipolar disorder, psychosis, active substance use disorder), and/or impaired cognition as operationalized by performance >1.5 SD below the normative mean on the Montreal Cognitive Assessment (MoCA; Rossetti et al., 2011).

Procedures

The data were collected in compliance with the UH institutional review board . Participants recruited at UH received extra research credit. Community participants received a gift card from a chain store and an optional written summary of their neurocognitive test results. Student research assistants tested participants in a single session in a quiet room. Basic characterization of the sample (see Table 1) was accomplished using a demographics questionnaire. The MoCA (Nasreddine et al., 2005) is a brief global screening measure (range 0–30) that was used both for exclusionary purposes prior to data analysis and for the characterization of the sample. The Word Reading subtest of the Wide Range Achievement Test – Version 4 (WRAT-4; Wilkinson & Robertson, 2006) is a widely used oral reading task that

Table 1. Demographic, health, and internet use characteristics of the study groups.

Participant Characteristic	Younger (*n* = 50)	Older (*n* = 41)	*p*-value
Age (years)	22.4 (3.8)	60.9 (7.0)	–
Education (years)	15.0 (1.4)	15.1 (2.4)	.666
WRAT-4 Reading			
Standard Score	103.4 (10.2)	104.9 (8.1)	.427
Grade equivalent	12.1 (1.2)	12.6 (0.7)	.030
Father's education (years)	14.4 (4.1)	13.0 (4.4)	.118
Sex (% women)	73	66	.528
Race/Ethnicity (%) [a]			.002
White	38	68	
Black	6	10	
Hispanic	32	10	
Employed (%)	68	66	.828
Technology or Health Field	18	20	
DSM5 psychiatric symptoms (of 88) [b]	16.8 (8.6)	9.6 (10.3	<.001
SCQ total health conditions	0.7 (0.9)	1.7 (1.5)	<.001
HBC Good Health Practices (of 5)	3.7 (0.6)	3.7 (0.6)	.093
eHEALS (of 32)	24.6 (4.3)	24.3 (4.9)	.692
Internet use (hrs/wk)	50.8 (14.1)	33.8 (21.2)	.002
Internet anxiety (of 24)	5.8 (3.0)	6.6 (3.7)	.464
Internet Speed at Testing [c]			
Pre–test ping (ms)	2.5 (1.4)	3.5 (4.2)	.379
Post–test ping (ms)	2.4 (0.9)	3.3 (4.5)	.026

Data represent M (SD) or % (percentages may not add up to 100% due to rounding or by item response options); eHEALS = eHealth Literacy Scale; HBC = Health and Behavior Checklist; ms = milliseconds; SCQ = Self-Administered Comorbidity Questionnaire; WRAT-4 = Wide Range Achievement Test, Fourth Edition. [a]Five participants declined to respond. [b]DSM5 = Diagnostic and Statistical Manual of Mental Disorders–5. [c] per speedtest.net.

was used as a measure of basic literacy. The total reading score was converted to a grade-level reading equivalent and an age-adjusted scaled score to generate an estimate of verbal intelligence. A modified version of the Level-1 Cross-Cutting Symptom measure from the Diagnostic and Statistical Manual of Mental Disorders (DSM-5; American Psychiatric Association, 2013) was used to assess psychiatric symptoms. The measure consists of 23 questions that assess 13 psychiatric domains with items that range on a 5-point scale from 0 (none or not at all) to 4 (severe or nearly every day). The item assessing for suicidal ideation was removed from the standard protocol, resulting in a modified scale with possible scores ranging from 0–88. The Self-Administered Comorbidity Questionnaire (SCQ; Sangha et al., 2003) allowed participants to note the presence of several common medical conditions, whether they are receiving treatment, and their perception of its impact on daily functioning. The eHealth Literacy Scale (eHEALS; Norman & Skinner, 2006) is a self-report measure of a participant's knowledge and perceived skills at finding, evaluating, and applying eHealth information (e.g., "I know how to find helpful health resources"). Responses were rated on a scale from 0 (strongly disagree) to 4 (strongly agree). The total score could range from 0 to 32, with a higher score indicating comfort with utilizing the internet for health-related purposes. The Good Health Practices subscale of the Health Behaviors Checklist (Vickers et al., 1990) is a brief survey of behaviors related to wellness maintenance, and includes general positive daily behaviors items such as "I exercise to stay healthy," "I don't smoke," and "I get enough sleep." Responses are rated on a scale from 1 ("Not at all like me") to 5 ("Very much like me"). Internet use frequency (Baggio et al., 2017) was measured by asking participants how often they used the internet in the previous 30 days, on an average weekday, and on an average weekend day. From these responses, a single score that accounted for quantity and frequency was calculated, with higher scores indicating more use (range = 0–63). Internet anxiety was measured using a brief questionnaire (Joiner et al., 2007) comprised of 6 questions about anxiety related to Internet use (e.g., "I always feel anxious when using the internet" and "My anxiety about using the internet bothers me."). Items were rated on a five-point scale from 0 (strongly disagree) to 4 (strongly agree).

eHealth search tasks

The eHealth task comprised of two subtasks: a fact-finding (i.e., Fact Search) and a symptom diagnosis (i.e., Symptom Search) task (Kordovski et al., 2020). The order of administration of each task was counterbalanced.

eHealth Fact Search

Participants were instructed to use the internet to answer five simple questions related to migraines (e.g., "What is the prevalence of migraines in the United States?"). Participants wrote out their answers using pencil and paper below each question. Four of the five questions can be answered by searching various websites. One question, however, directs participants to a specific resource (i.e., "According to the Mayo Clinic, what is the definition of migraine?"). The task had a Flesch Kinkaid Reading Grade Level of 6.0. Each item was scored as either correct (1) or incorrect (0), yielding a range of scores from 0 to 5. Participants were allowed up to 5 minutes to complete the task and could choose their preferred internet browser (e.g., Safari or Mozilla Firefox) and search engine (e.g., Google, Yahoo, Bing). The outcome variables of interest included accuracy (0 to 5) and completion time (0 to 300 seconds).

eHealth Symptom Search

Participants were provided a short vignette describing a fictional scenario in which they began experiencing multiple symptoms after a hiking trip. The vignette had a Flesch Kinkaid Reading Grade Level of 9.1 and stated:

> Imagine that you have had a severe headache and general fatigue for the past seven days since you returned from a hiking trip. You had difficulty moving your head when you woke up this morning and discovered a rash on your leg.

After being presented with the vignette, participants were asked to generate a plausible diagnosis, rate their confidence in that diagnosis (range: 1–100), and rate their confidence in their ability to use the internet to arrive at a final diagnosis (range: 1–100). Next, participants were instructed to use the internet to find a potential diagnosis for the condition described in the vignette. They were allowed up to 10 minutes to complete the task and could choose their preferred browser and search engine. The participants alerted the examiner when they had arrived at a diagnosis, provided their response verbally, and were asked to rate their confidence in the final diagnosis (range: 1–100). Diagnoses were scored on a 2-point scale. Full credit (i.e., 2 points) was awarded if the participant correctly identified the condition as Lyme disease. Partial credit (i.e., 1 point) was awarded if the participant's answer was a related condition that contained some of the presented symptoms (e.g., meningitis or "tick bite"). The participant was assigned 0 points if they provided an incorrect answer (e.g., migraine, flu) or if they did not provide a response. The outcome variables of interest included accuracy (0–2) and completion time (0–600 seconds).

Participants were also asked to state which webpage was the most helpful in arriving at their final diagnosis. Data collected from this program included the URLs visited, the title of the web pages, and the participants' search queries. The participants' chosen website was analyzed for credibility based on information accountability guidelines established by the American Medical Association (Winker et al., 2000). Websites were coded according to 16 criteria (Hong, 2006), including factors like domain (e.g., .gov) and third-party endorsements.

Assessment of executive functions

Performance-based

Participants completed a brief battery of executive functions that assessed the subdomains of novel problem-solving, cognitive flexibility, and verbal fluency. Specifically, participants completed: 1) the 20-Questions subtest of the Delis-Kaplan Executive Function System (D-KEFS; Delis et al., 2001), from which the raw Initial Abstraction score was used (range = 0–60); 2) the D-KEFS Trail Making Test (TMT), from which the raw completion time for Condition 4 (Letter-Number Sequencing) was used; and 3) the action (verb) fluency test, from which the raw total score was used (Piatt et al., 2004). These subdomains align with theories of information search (e.g., Marchionini & White, 2007; Norman, 1998) and fall under the umbrella of executive functions (Miyake et al., 2000; Zelazo et al., 1997). In addition, these measures were chosen based on prior work showing the relationship between internet search behavior and the subdomains of rapid set-shifting (e.g., Trail Making Test – Part B; Dommes et al., 2011; Sharit et al., 2015) and abstract reasoning (e.g., Inference Test; Czaja et al., 2010; Sharit et al., 2008). Given the prior relationship between keyword generation and vocabulary (Dommes et al., 2011), we suspected verbal fluency might capture the verbal abilities require to generate relevant keywords in the search process. For data reduction purposes, a single executive factor was extracted using principal components analysis (PCA) on the raw scores (See Table 2). The single factor (eigenvalue 1.54) explained 51.48% of the variance and was used as a composite score for all analyses.

Self-reported

Raw total scores from the Frontal Systems Behavior Scale (FrSBe; Grace & Malloy, 2001) were analyzed separately since performance-based and self-report measures of executive functions tend to show weak relationships with one another in the literature (Toplak et al., 2013) and in this sample (r = .066, p = .534).

Assessment of other neurocognitive measures

We assessed for other cognitive domains that would allow us to determine the specificity of the mediating effects of executive functions on the relationship between age and eHealth search performance.

Memory

A modified administration of the California Verbal Learning Test-Second Edition Short Form (CVLT-II SF; Delis et al., 2000) was administered as a used to measure of auditory-verbal learning and memory. Raw scores of these cognitive tests were converted to sample-based z-scores . The memory composite comprised of the CVLT-II SF Total Trials 1–4, Short Delay Free Recall, and Long Delay Free Recall (Mean

Table 2. Results from the principle component analyses of cognitive variables.

Test	Factor Loading	Intercorrelations			
Performance-Based Executive Functions Factor		DKEFS NLS	DKEFS 20QIA	Action Fluency	
DKEFS TMT Number Letter Sequencing (NLS)	.643	1.00	–	–	
DKEFS 20Q – Initial Abstraction (IA)	−.712	−.176	1.00	–	
Action Fluency	.791	−.347	.285	1.00	
Processing Speed/Attention Factor		CVLT-II Trial 1	WAIS-IV DSF Total	DKEFS VS	DKEFS MS
CVLT-II-SF Trial 1	−.687	1.00	–	–	–
WAIS-IV Digit Span Forward (DSF)	−.391	.213	1.00	–	–
DKEFS TMT Visual Scanning (VS)	.790	−.323	−.142	1.00	–
DKEFS TMT Motor Speed (MS)	.656	−.191	−.005	.396	1.00
Memory Factor		CVLT-II-SF Total	CVLT-II-SF SDFR	CVLT-II-SF LDFR	
CVLT-II-SF Total 1–4	.859	1.00	–	–	
CVLT-II-SF Short Delay Free Recall (SDFR)	.917	.659	1.00	–	
CVLT-II-SF Long Delay Free Recall (LDFR)	.922	.674	.805	1.00	

DKEFS = Delis-Kaplan Executive Function System; TMT = Trail Making Test; 20Q = 20 Questions.

correlation = .71). A PCA was conducted (see Table 2) and a single factor was extracted from the three raw scores on the memory measurers (eigenvalue 2.43), which explained 80.9% of the variance. The PCA composite score was used for all analyses.

Attention and speed

The Digit Span subtest of the Weschler Adult Intelligence Scale-IV (WAIS-IV; Wechsler, 2008) was administered as a test of attention. We also used Trial 1 of the CVLT-II SF as an additional measure of auditory attention. Basic processing speed was measured with the raw completion time of Conditions 1 and 5 from the D-KEFS Trail Making Test. Condition 1 is a visual search task that required participants to scan a page and cross out the "3"s on the page. Condition 5 is a motor speed task that required participants to trace over a dotted line on a page as quickly as possible (Delis et al., 2001). An initial PCA was conducted and showed that two factors could be extracted from the four raw scores. The first factor (eigenvalue 1.68) showed high loadings for three of the four cognitive variables in the expected directions (i.e., higher scores on the processing speed factor were associated with longer times on DKEFS TMT tests and lower CVLT-II-SF scores) and explained 42% of the variance. The second factor (eigenvalue = 1.04) included only Digit Span Forward (.800); however, because the other loadings variables were small and in the unexpected direction, and we ultimately decided to not include the second factor in any subsequent analyses. Note that, findings did not differ if we simply used a raw mean composite score comprised of all 4 tests in this domain.

Data analyses

Visual inspection and screening of the data were performed to ensure accuracy and to identify outliers (Van Den Broeck et al., 2005). Data for all tests with outliers underwent 95% Winsorization (Hastings et al., 1947). Less than 5% of the data were missing. The missing data were confirmed to be missing at random using Little's MCAR test and imputed with an expectation-maximization method. Two-tailed t-tests were used to analyze group differences in variables that were normally distributed (or a Wilcoxon Rank Sum test for non-normal distributions). T-tests, correlations, and regression analyses were conducted using JMP pro software package (version 14.0; SAS, Cary, NC). Principal component and mediation analyses were conducted using IBM SPSS (version 26.0, Armonk, NY). An examination of the Kaiser-Meyer Olkin (KMO) measure of sampling adequacy for all variables suggested that the sample was acceptable (KMOs range .585 to .731). The mediation method conditional process modeling (PROCESS v3.4) with bootstrapping (5000 samples), proposed by Hayes et al. (2017), was used to assess the mediating effects of cognition on the relationship between age and search task performance. A mediation approach was chosen because of the known direct influence of aging on cognitive functioning, which in turn is hypothesized to influence search behavior. Given our interest in parsing out the unique role of executive functions above other cognitive domains, we considered multiple cognitive domains, where relevant, in parallel models. This minimized the risk of type I error while being able to assess key covariates in a parsimonious model. Critical alpha was set to .05. Given the small sample sizes, a confounder approach was used in determining covariates (Field-Fote, 2019) whereby any variable in Table 1 was included as a covariate if it differed by age group *and* was related to the dependent variable of interest.

Results

Participants

Five participants (four older adults and one younger adult) were excluded due to below-criterion MoCA scores, and one younger adult was excluded due to current severe substance use. The analyzable sample, therefore, included 50 younger and 41 older adults whose characteristics are displayed in Table 1. Older adults had higher reading literacy, fewer psychiatric symptoms, more comorbid health conditions, a higher proportion of white participants, less internet use per week, and slower internet speed at the end of testing (all ps<.05). Thus, these were considered individually as potential mediators for inclusion in the models below, with their adoption being contingent on their association with the primary outcomes. The groups were comparable on all other sociodemographic, health, and other internet use characteristics (ps>.05). Older adults performed worse than younger adults on all unadjusted cognitive measures, except for Digit Span Forward and action fluency (ps>.05; Table 3).

Age group and cognitive effects on eHealth search task speed

eHealth Fact Search speed

Descriptive data are displayed in Table 4, and the correlations between age group, cognitive predictors, and search outcomes are presented in Table 5. The DSM-5 Cross-Cutting Symptom measure was the only variable in Table 1 that met criteria for inclusion as a covariate. The model with eHealth Fact Search time as the dependent variable, age group as the independent variable,

Table 3. Cognitive characteristics of the study groups.

Cognitive Variable	Younger (n = 50)	Older (n = 41)	p-value
MoCA			
Raw Score	26.3 (2.4)	25.3 (2.3)	.037
Normative z-score	0.2 (0.9)	0.3 (0.7)	.343
WAIS-IV Digit Span Forward	10.1 (2.1)	9.9 (2.4)	.636
CVLT-II-SF Trial 1	6.1 (1.2)	5.2 (1.6)	.003
CVLT-II-SF Total (Trials 1–4)	30.0 (2.7)	27.0 (5.8)	.001
CVLT-II-SF Short Delay Free Recall	8.1 (0.9)	7.4 (1.7)	.020
CVLT-II-SF Long Delay Free Recall	7.7 (1.2)	6.9 (1.8)	.015
D-KEFS 20-Questions (of 60)	38.5 (16.1)	29.4 (14.2)	.006
D-KEFS TMT Condition 1 (sec)	19.1 (4.5)	23.2 (0.8)	.0004
D-KEFS TMT Condition 4 (sec)	65.7 (19.0)	85.1 (43.2)	.005
D-KEFS TMT Condition 5 (sec)	22.2 (8.2)	31.0 (12.6)	.0001
Action (verb) Fluency	19.9 (6.6)	17.4 (5.8)	.061
FrSBe Total (of 230)	95.7 (18.8)	85.8 (18.7)	.014

Data represent M (SD); CVLT-II-SF = California Verbal Learning Test II Short Form; D-KEFS = Delis-Kaplan Executive Functions Scale; FrSBe = Frontal Systems Behavior Scale; MoCA = Montreal Cognitive Assessment; TMT = Trail Making Test, WAIS-IV = Weschler Adult Intelligence Scale – IV.

and DSM-5 Cross-Cutting Symptom Measure total as the only covariate was significant (F[2, 88] = 8.29, p < .001, adjusted R^2 = .14). Age group (β = −21.9, 95% confidence interval [CI] = −41.20, 2.67, p = .026) emerged as a significant predictor such that younger age was associated with faster task performance (Cohen's d = 0.48). The DSM-5 Cross-Cutting Symptom Measure was also a significant covariate (β = −1.14, 95% CI = −2.10, −0.18, p = .021), such that more psychiatric symptoms were associated with slower task performance (partial r = 0.24). Performance-based executive functions did not emerge as a significant mediator of age and Fact Search speed (ab_{EF} = −1.359, 95% CI = −8.937, 5.816).

eHealth Symptom Search speed

No variable in Table 1 met criteria for inclusion as a covariate. As such, eHealth Symptom Search time was also examined with age group as the independent variable with no additional covariates. The resulting model was not significant (F[2, 88] = 2.83, p = .183, adjusted R^2 = .02). Similarly, performance-based executive functions did not emerge as a significant mediator of age and Symptom Search speed (ab_{EF} = −19.343, 95% CI = −6.102, 59.929).

Table 4. Descriptive data for eHealth search task performance by age group.

eHealth Search Variable	Younger (n = 50)	Older (n = 41)
Fact Search		
Time (seconds)	251.2 (49.2)	281.3 (36.8)
Percentage completed within time	72%	32%
Accuracy (of 5)	4.0 (0.8)	2.8 (1.4)
Final website quality code (of 16)	12.4 (0.8)	12.0 (1.4)
Symptom Search		
Time (seconds)	258.3 (147.9)	306.0 (191.3)
Pre-Search		
Guess accuracy (of 2)	0.2 (0.6)	0.7 (0.8)
Guess confidence (of 100)	44.1 (25.1)	57.4 (27.3)
Confidence in Internet use (of 100)	60.7 (26.0)	64.8 (28.8)
Post-Search		
Response accuracy (of 2)	0.8 (0.7)	1.1 (0.8)
Response confidence (of 100)	58.9 (26.4)	71.7 (25.3)
Full credit score of 2 (%)	18	42
Improved following search (%)	12	24
Final website quality code (of 16)*	11.7 (2.0)	10.6 (2.6)

Data represent M (SD) or percent. *4 participants (1 younger adult, 3 older adults) did not report a single website as most helpful.

Age group and cognitive effects on eHealth search task accuracy

eHealth Fact Search accuracy

The number of total health conditions was the only variable in Table 1 that met criteria for inclusion as a covariate. Age group and total health conditions were entered into the model predicting eHealth Fact Search accuracy. Descriptive data are displayed in Table 4. The overall model was significant (F[2,88] = 13.5, p < .001, adjusted R^2 = .22), within which age group was a significant predictor (β = 1.06, 95% CI = .28, .77, p < .001). Specifically, younger adults were more accurate than older adults on the eHealth Fact Search task (d = .91). Total number of health conditions was not a significant predictor in this model (β = −1.30, 95% CI = −.32, .06, p = .170, partial r = .29).

Table 5. Correlations between age, cognition, and eHealth search performance.

Variable	1	2	3	4	5	6	7	8	9	10	11
(1) Age Group	–										
(2) Fact Search accuracy	−.468**	–									
(3) Fact Search speed	.352	−.289**	–					−.036	.169	−.042	−.035
(4) Symptom Search accuracy	.220*	.142	.017	–				.281	−.138	.207	−.053
(5) Symptom Search speed	.141	−.178	.181	−.181	–						
(6) WRAT-4 Reading Grade	.200	.075	−.007	.349**	.000	–					
(7) DSM5 psychiatric symptoms	−.358**	−.036	−.331**	.041	.025	−.220	–				
(8) Executive Functions	−.351**	.428**	−.080	.288*	−.192	.071	.141	–			
(9) Attention/Speed	−.460**	.481**	.165	−.144	−.237*	−.044	−.016	.502**	–		
(10) Memory	−.303**	.388**	−.046	.211*	−.044	.049	.019	.460**	.458**	–	
(11) FrSBe Total	−.256*	−.073	−.221*	−.110	−.049	−.275	.586**	.066	.060	−.053	–

Correlations with Age group represent point-biserial correlations. Correlations above the diagonal line are partial correlations between the search variables and cognitive variables controlling for relevant covariates. * = p < .05 ** = p < .01 DSM5 = Diagnostic and Statistical Manual of Mental Disorders–5. FrSBe = Frontal Systems Behavior Scale; WRAT-4 = Wide Range Achievement Test, Version 4.

Despite the unexpected age group difference on this task, we examined executive functions as a possible mediator of the observed findings. No variables in Table 1 met inclusion criteria as a covariate. In a simple mediation model that included performance-based executive functions, there was a significant and negative direct effect of age and a negative indirect effect of executive functions (Table 6). Next, to test the specificity of executive functions compared to lower-order functions, we first included speed/attention as a parallel mediator. The resulting model was significant, and there was a significant direct effect of age (c' = .718, 95% CI = −1.212, −.229), and indirect effect of performance-based executive functions (ab_{EF} = −.183, 95% CI = −.441, −.009) and speed/attention (ab_{AS} = −.291, 95% CI = −.610, -.031; Figure 1). Third, a simple mediation model that included memory was also significant (Table 6); however, memory was no longer a significant mediator when speed/attention was included in the model (95% CIs included 0). Lastly, in a single mediation model that examined self-reported executive functions, there was a significant and negative direct effect of age group but no indirect effect of self-reported executive functions (Table 6). In sum, only performance-based executive functions mediated the relationship between age and Fact Search accuracy, independent of speed/attention.

eHealth Symptom Search accuracy

WRAT-4 Reading Grade and race/ethnicity were the only two variables in Table 1 that met the criteria for inclusion as covariates. In the model predicting eHealth Symptom Search accuracy, age group was the primary independent variable, with race/ethnicity and WRAT-4 Reading Grade as covariates. The overall model was significant (F [5,83] = 4.46, p = .001, adjusted R^2 = .16), with WRAT-4 Reading Grade emerging as the sole contributor (β = .23, 95% CI = .08, .39, p = .003). Neither age group (β = −.06, 95% CI = −.23, .10, p = .452, d = .16) nor race/ethnicity (p > .05) significantly contributed to the model. Therefore, there were no differences in accuracy performance between older and younger adults.

In the planned mediation models that included both performance-based executive functions, only WRAT-4 Reading Grade met the criteria for inclusion as a covariate. In a simple mediation of model that included performance-based executive functions as a mediator of age and Symptom Search accuracy, there was a significant and positive direct effect of age and a negative indirect effect of executive functions (Table 5). To test the specificity of executive functions compared to lower-order functions, we then added speed/attention as a parallel mediator. The resulting model was significant, and there was a significant positive direct effect of age (c' = .539, 95% CI = .200, .879), and a negative indirect effect of performance-based executive functions (ab_{EF} = −.196, 95% CI = −.377, −.055), but not speed/attention (ab_{AS} = −.097, 95% CI = −.284, .071; Figure 2). The opposing directions of the direct and indirect effects signal a competitive mediating effect of performance-based executive functions (Zhao et al., 2010). WRAT-4 Reading Grade also emerged as a significant predictor of Symptom Search accuracy

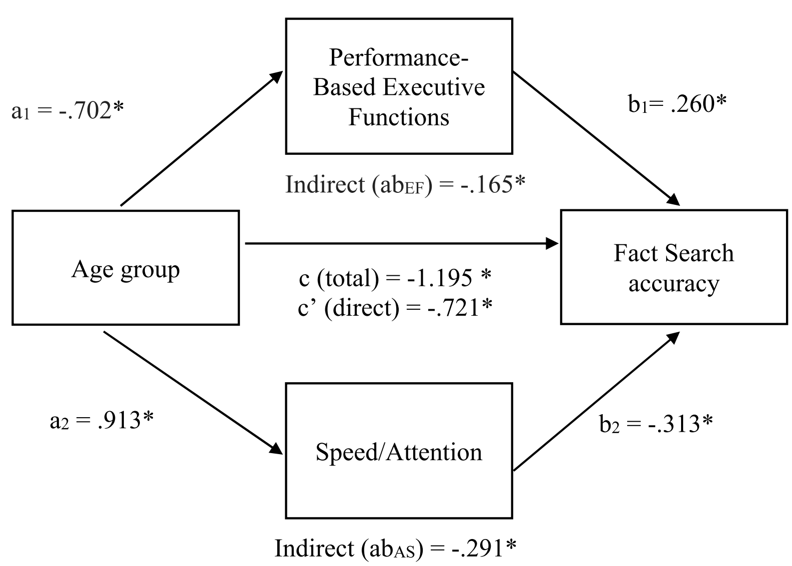

Figure 1. Mediation model of age, performance-based executive functions, speed/attention and Fact Search accuracy. Unstandardized regression coefficients for the relationship between age and accuracy on the Fact Search task as mediated by performance-based executive functions and attention/speed. *Confidence Intervals did not include 0.

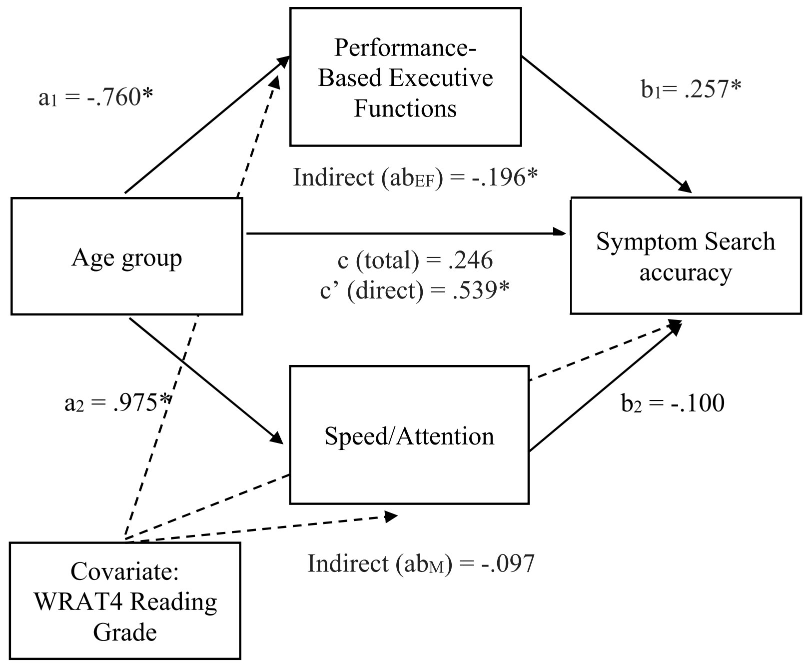

Figure 2. Mediation model of age, performance-based executive functions, speed/attention, and Symptom Search accuracy. Unstandardized regression coefficients for the relationship between age and accuracy on the Symptom Search task as mediated by performance-based executive functions and motor speed. *Confidence Intervals did not include 0.

(β = .246, CI = .091, .401). Third, a simple mediation model that included memory was significant (Table 5), and it remained significant when speed/attention was included in the model (ab_{Mem} = −.108, 95% CI = -.252, -.002). The incremental utility of memory was assessed in one final model that included executive functions, speed/attention, and memory as parallel mediators. The resulting model was significant, and executive functions emerged as the only significant mediator (ab_{EF} = −.172, 95% CI = -0.344, −0.033). Lastly, in a single mediation model that examined self-reported executive functions, there was no effect of age group or self-reported executive functions (Table 5).

We also examined if prior knowledge or exposure to Lyme disease may have influenced our findings. On a posttest questionnaire, only three participants in the current sample, all of whom were older adults, reported having been exposed to or knew of someone with Lyme disease. Older adults also had generally better pre-search Symptom Search guess scores and were more likely to have guessed a full-credit answer (χ^2 = 4.7, p = .03) in the pre-search stage. The main analyses were repeated in the subset of participants who did correctly identify Lyme disease pre-search (n = 77), and all findings described above were maintained.

Age group effects on eHealth search task website reliability

As shown in Table 3, younger adults landed on websites with a higher AMA Reliability Score on both the eHealth Fact (Z = −2.20, p = .028, d = .36) and Symptom (Z = −2.21, p = .023, d = .48) search tasks. Final website rating was not related to task completion time in either the Fact (ρ = −0.14, p = .188) or Symptom (ρ = .06, p = .596) search tasks. Interestingly, final website rating was also not related to accuracy in either the Fact (ρ = .18, p = .095) or Symptom (ρ = .05, p = .683) search tasks. These null findings remained when examined only in the older adult sample (*ps* >.05). No potential covariates met criteria for inclusion in these analyses.

Discussion

Older adults are increasingly using the internet for health-related activities that influence their medical decision-making, but are also at risk for experiencing problems identifying and using accurate eHealth information (e.g., Sharit et al., 2008). The current study examined the effects of age on eHealth search behavior, including the potentially mediating effects of executive functions. Partially consistent with the first hypothesis regarding performance speed, there was a medium-sized effect of older age on completion time on the eHealth Fact Search task. Importantly, this finding was independent of relevant clinicodemographic covariates. Although the Fact Search task was originally regarded as the more simple and structured of the two eHealth search tasks in this study, it nevertheless involves a mildly complex integration of motor (e.g., computer peripherals) and cognitive (e.g., quickly generating search terms, filtering search hits) speed tasks. This finding is largely consistent with studies showing that older age is associated with slower speed on health and non-health search tasks (e.g., Pak et al., 2009; Sharit et al., 2015). Results also mirror observations in the cognitive literature showing associations of older age with slowed general processing speed (e.g., Salthouse, 2000), which can affect aspects of everyday functioning in older age (Wahl et al., 2010).

Contrary to expectations, older adults were no slower than their younger counterparts on the less structured Symptom Search task. This unexpected finding is nevertheless consistent with prior reports of no age-related differences in performance speed on complex search tasks (Dommes et al., 2011), wherein complexity was regarded as how easy it was for an individual to produce pertinent keywords to obtain a correct answer. A null age effect of total performance task speed may not necessarily mean there are no age-related differences. Indeed, while Chevalier et al. (2015) did not find age effects on search time, older adults spent more time on the search engine. The interpretation was that older adults spent less time in the planning stages (i.e., elaborating a plan to achieve the search goal), more time evaluating the website before clicking the link to navigate the page, and less time on the actual web page. If the older adults in the current study behaved similarly, this did not prove to be beneficial since, overall, older adults generally chose less reliable or trustworthy websites. The results suggest that the search process may be fundamentally different for structured versus open-ended search tasks. The small and non-significant correlation between accuracy performance on these two tasks in this study lends further support to this idea (ρ = .17, p = .109).

Also contrary to expectations, older adults were less accurate than younger adults on the structured eHealth Fact Search task. This difference was associated with a large effect size and was not confounded by any sociodemographic, health, or internet variables measured in this study. One possibility is that older adults were less accurate because they were slower. Indeed, a far greater proportion of older adults failed to complete the fact-search task within the allotted time (Table 4). Furthermore, post-hoc analyses show that time and accuracy were negatively correlated in the full sample for the eHealth Fact Search task ($\rho = -.45$, $p < .001$), but not in the eHealth Symptom Search task (ρ = .11, p = .319). Furthermore, mediation analyses demonstrated a significant indirect path of speed/attention on eHealth Fact Search accuracy, but not eHealth Symptom Search accuracy in the models with performance-based executive functions. This suggests a difference in the mediating effects of speed on these two different eHealth search tasks. Some work also suggests that older adults voluntarily minimize errors at the expense of reduced time (i.e., time-accuracy trade-off), whereas younger adults generally tend to balance speed and accuracy evenly (Starns & Ratcliff, 2010). Additional work, incorporating measures that isolate cognitive speed and perceptual speed from basic motor skills, will allow for a better understanding of each mechanism in different aspects of the search process (e.g., Sharit et al., 2008).

That said, executive functions mediated the effects of age on eHealth search accuracy in both the Fact and Symptom search paradigms, even when controlling for lower-order functions such as attention and motor speed. Therefore, executive functions show some degree of specificity in their relationship with both Fact and Symptom Search accuracy. The relationship between executive functions and Fact accuracy was unexpected, as the eHealth Fact Search task was intended to be relatively straightforward. In addition, our pilot work did not show significant associations with executive functions in young adults (Kordovski et al., 2020). However, the current findings suggest that executive functions may partly explain the age effects on eHealth searches for information that might otherwise appear simple. So even straightforward information search tasks such as looking up a definition of a health term or details about a diagnosis may not be as simple as they appear on the surface. This could mean that eHealth search tasks are more difficult for older adults. Older adults lived most of their lives without the internet and may therefore have less general computer and internet literacy. Although these constructs were not measured separately, such generational differences create added burden to the older adults, who then rely more strongly on executive networks to complete "basic" tasks, thus rely more heavily on higher-order cognitive resources to perform successfully. As such, older adults who have better executive abilities are more successful in their search efforts. Conceptually, mediating effects of executive functions align with cognitive models of information search (e.g., Marchionini & White, 2007; Norman, 1998), suggesting that problem-focused search involves factors such as planning, executing, and judgment (Zelazo et al., 1997). Several lines of evidence show declines in executive functions (Jurado & Rosselli, 2007) and accompanying neuroanatomical changes (e.g., Nyberg et al., 2010) in typically aging adults. Further, executive functions are among the strongest cognitive predictors of functional status (e.g., Grigsby et al., 1998; Royall et al., 2004), and brain areas that support executive functions (e.g., prefrontal areas) have been implicated in internet search (e.g., Dong & Potenza, 2015, 2016; Small et al., 2009).

Interestingly, a competitive mediation effect of performance-based executive functions (Figure 2) was observed, such that the indirect effect of age on Symptom Search through performance-based executive functions was negative, but the direct effect was positive. Given the overall positive total effect observed, the model suggests that older age was ultimately beneficial to search performance despite age's negative effect on executive functions, which positively impacts search performance accuracy. Age-related increases in health knowledge are one proposed mechanism by which this may occur. For example, older adults may have been more familiar with Lyme disease and, therefore, more likely to get the correct answer. While our older adult sample did include participants who had some prior exposure to somebody with Lyme disease and was overall more likely to have guessed the correct answer in the pre-search phase, our analyses suggest that knowledge about Lyme disease was not necessarily a confounding factor. Another possible explanation is that older adults have a general fund of health knowledge due to having more general life experience or living with multiple conditions that may have been advantageous to overall performance. This is a testable explanation. General internet knowledge is an important predictor for performance on non-eHealth internet search tasks, particularly on complex problems (Sharit et al., 2008), and explains variance in performance beyond the influence of cognitive abilities in older adults (Czaja et al., 2010). In the current study, greater general health knowledge (e.g., base rates of other diseases) may have aided the older adult sample in narrowing down the possible conditions to the correct one. Future studies may wish to add measures of health knowledge and internet knowledge to assess the role of health knowledge and health-related internet search skill.

In order to examine the specificity of our findings regarding executive functions, we tested the possible mediating role of memory, given it is a closely related higher-order construct that also declines with age and is associated with internet navigation skills (Woods et al., 2019). Interestingly, we found that memory, similar to executive functions, mediated the relationship between age and Fact Search accuracy (Table 6). One reason for this is that good recollection of the question content improved the efficiency in which people searched for information. That is, participants who could read the question on the record form and then spend time searching for the answer without reviewing the prompts. In partial support of this, the mediating effect of memory was not maintained when speed/attention and executive functions were added as parallel mediators. In other words, memory did not independently mediate the relationship between age and Symptom Search accuracy. This is notable because the Symptom Search task was designed to be a more complex, cognitively demanding, and less structured task, which was expected to show stronger relationships with executive functions. Overall, executive functions were the only higher-order cognitive construct that independently mediated both Fact Search and Symptom Search task accuracy.

Finally, the results did not show a significant mediating effect of self-reported executive functions. This finding is consistent with several converging lines of evidence showing that self-report and performance-based measures are generally weakly correlated in older adults (e.g., Schmitter-Edgecombe et al., 2011). However, one possibility for the null findings is that our measures of self-reported executive functions do not capture the functions that are most relevant for internet search. Indeed, the FrSBe measures behavioral manifestations of executive dysfunction (e.g., symptoms of apathy, disinhibition, and executive functions) that are associated with frontal lobe injury. In contrast, our findings found that normal variation in verbal fluency, set-shifting, and concept formation was associated with search accuracy. It is possible that other self-report measures of executive function that tap into comparable constructs may be important predictors of internet search.

Limitations and conclusions

This study has several limitations that are important to consider. First, as noted above, there were aspects of the task that may have resulted in a confounding effect of performance speed on accuracy and the quality of the final websites on which participants based their answers. However, it is important to note that website reliability rating was not significantly related to task accuracy or completion time. Future studies that use this paradigm with older adults may wish to extend the discontinue time to allow more time for task completion. Second, the generalizability of the study is limited, as only 5 participants were over 70 years old, which may have limited power to detect age-related effects. Relatedly, future studies should include all age groups to allow for the examination of age as a continuous variable. Within the older adult group, age as a continuous variable was not related to any of the eHealth task primary outcomes (*p*s>.05). Another limitation is that the older adult sample was predominantly White, had relatively high levels of reading and health literacy, and was generally well-skilled at using the internet. Fourth, while the unstructured nature of the search tasks was designed to replicate naturalistic internet search queries, the external validity of the tasks should be investigated further in future studies, particularly since we know that eHealth is only one part of a broader array of health behaviors. Fifth, although we included measures of attention and verbal learning/memory, the influence of other domains such as sustained attention, visuospatial abilities (e.g., visual working memory), semantic memory, perceptual reasoning, and meta-cognition were not included but certainly warrant further examination. Further, we did not include measures that allowed us to fully examine divergent validity, although this is challenging for a multi-faceted process like information search. Finally, the mediation analyses were completed on a cross-sectional dataset and should be extended to a longitudinal design.

Despite these limitations, findings from this study have practical relevance. The findings suggest that increasing age is associated with problems in some, but not all, aspects of health information search. Specifically, older adults may require longer amounts of time to search for health information, but they are not necessarily less accurate in their searches. Furthermore, executive functions are important contributors to eHealth search behavior in older adults. The current findings suggest that websites targeted for an older audience should be created with an interface suitable for those with compromised executive abilities. This may include organizing information in a simple manner, highlighting key points, and minimizing advertisements and other distracting elements. Declines in executive functions are not only common in normal healthy aging but are common in many clinical conditions. It is important for clinicians to appreciate the multitude of ways that executive functions can impact daily life and health management when working with clinical populations. The inclusion of commonly used neuropsychological tests in the current study helps aid the interpretation of these findings in neuropsychological settings and guide recommendations. In an era of rampant spread of misinformation, these findings underscore the potential role of cognitive abilities in supporting an individual's ability to evaluate the quality and accuracy of available health information. Much more work in this area is certainly needed.

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ORCID

Victoria M. Kordovski http://orcid.org/0000-0001-5340-7304
Luis D. Medina http://orcid.org/0000-0001-8163-7772

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