Your Brain on Google: Patterns of Cerebral Activation during Internet Searching

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Objective: *Previous research suggests that engaging in mentally stimulating tasks may improve brain health and cognitive abilities. Using computer search engines to find information on the Internet has become a frequent daily activity of people at any age, including middle-aged and older adults. As a preliminary means of exploring the possible influence of Internet experience on brain activation patterns, the authors performed functional magnetic resonance imaging (MRI) of the brain in older persons during search engine use and explored whether prior search engine experience was associated with the pattern of brain activation during Internet use.* **Design:** *Cross-sectional, exploratory observational study* **Participants:** *The authors studied 24 subjects (age, 55–76 years) who were neurologically normal, of whom 12 had minimal Internet search engine experience (Net Naive group) and 12 had more extensive experience (Net Savvy group). The mean age and level of education were similar in the two groups.* **Measurements:** *Patterns of brain activation during functional MRI scanning were determined while subjects performed a novel Internet search task, or a control task of reading text on a computer screen formatted to simulate the prototypic layout of a printed book, where the content was matched in all respects, in comparison with a nontext control task.* **Results:** *The text reading task activated brain regions controlling language, reading, memory, and visual abilities, including left inferior frontal, temporal, posterior cingulate, parietal, and occipital regions, and both the magnitude and the extent of brain activation were similar in the Net Naive and Net Savvy groups. During the Internet search task, the Net Naive group showed an activation pattern similar to that of their text reading task, whereas the Net Savvy group demonstrated significant increases in signal intensity in additional regions controlling decision making, complex reasoning, and vision, including the frontal pole, anterior temporal region, anterior and posterior cingulate, and hippocampus. Internet searching was associated with a more than twofold increase in the extent of activation in the major regional clusters in the Net Savvy group compared with the Net Naive group (21,782 versus 8,646 total activated voxels).* **Conclusion:** *Although the present findings must be interpreted cautiously in light of the exploratory design of this study, they suggest that Internet searching may engage a greater extent of neural circuitry not activated while reading text pages but only in people with prior computer and Internet search experience. These observations suggest that in middle-aged and older adults, prior experience with Internet searching may alter the brain's responsiveness in neural circuits controlling decision making and complex reasoning.*(Am J Geriatr Psychiatry 2009; 17:116–126)

Key Words: Brain activation, functional MRI, Internet search, middle-age and older adults, computer experience

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Recent research suggests that spending time in mentally challenging tasks may improve brain health and delay cognitive decline.[1,2] With the rapid growth of computer technology and the use of the Internet in recent years, many people are engaging in the mental challenge of going online one or more times each day. Although younger individuals are more likely to use the Internet—88% of people aged 18–29 years currently go online—a large proportion of middle-age and older adults use the Internet regularly.[3] The Pew Internet & American Life Project reported on Internet use patterns between January 9 and February 4, 2006, in a sample of 2,000 adults and found that 72% of people aged 51–59 years and 54% of those between age 60 and 69 years went online.[4] On a typical day, nearly 50% of online activities involve searching the Internet for information; 40% of people aged 50–64 years and 27% of those aged 65 and older are performing such searches.[5]

As the brain ages, a variety of structural and functional changes occur, including increased atrophy, regional reductions in glucose metabolism, and deposition of amyloid plaques and tau tangles.[6] These structural and functional alterations are associated with declines in processing speed, inhibitory control, and working memory, among other cognitive abilities.[7] Routine computer and Internet use may have an impact—both positive and negative—on the aging brain and these cognitive functions.[8–10] The brain effects of computer activities, particularly video gaming, have been explored in young adults and children.[11–13] Although the repeated mental activity of searching for information on the Internet could alter brain activation patterns in older adults, previous studies have not assessed brain function during search engine use and whether the degree of prior search engine use influences the extent and level of activations.

Activation imaging, which compares brain activity while subjects perform a task relative to a control or resting state, may reveal subtle alterations in brain function that may not be reflected in cognitive changes as measured by standardized neuropsychological testing.[14] Functional magnetic resonance imaging (MRI) provides measures of signal intensity associated with relative cerebral blood flow during memory or other cognitive tasks.[15] Activation imaging techniques offer a useful strategy for studying brain effects of mental stimulation, and recent studies support the possible role of such mental stimulation in preserving brain function.[1,2] Moreover, the Internet is an attractive technology for potentially enhancing brain function. Despite rapid growth in various computer-based tools claiming to enhance cognitive ability and brain function, there is a relative dearth of research supporting the effects of enhanced cognitive activity on brain function.[16–18]

In the present study, we focused on measuring brain activation patterns related to cognitive tasks involved in searching online. Because practice of mental tasks has been found to alter neural activation patterns,[19] we hypothesized that prior experience of using online search engines would influence activation patterns. In particular, we examined the difference in brain activity in a task that emulated the normal reading processes to gain knowledge about specific subjects, in comparison with an Internet search task, wherein the user actively seeks out and chooses the most relevant information. We hypothesized that actively searching for information would preferentially engage neural circuits involved in integrating semantic information, working memory, and decision making, specifically in dorsal and ventral prefrontal cortex. To address these issues, we performed functional MRI of the brain in older persons during search engine use and determined whether prior search engine experience influenced the degree and extent of activations.

METHODS

Study Subjects

We studied 24 neurologically normal subjects with technically adequate MRI scans of the brain. These subjects were selected initially from a pool of 76 potential subjects recruited through advertisements. From this pool of subjects aged 55–78 years, we excluded left-handed volunteers and anyone who had dementia, other medical, psychiatric or neurologic conditions, including cerebrovascular disease or uncontrolled hypertension, or took drugs that could influence cognition. All subjects completed a questionnaire for rating their frequency of computer and Internet use (1–5 scale) and their self-assessment of Internet expertise (1–4 scale). Based on the results of the questionnaire, subjects were assigned to one of two groups: the Net Naive group (minimal prior search engine experience) or the Net Savvy group (more extensive prior experience with computers and the Internet), until at least 14 subjects were enrolled in each group. A total of 28 subjects received magnetic resonance (MR) scans, and four of them with technically inadequate scans were excluded. One subject was excluded due to excessive head motion, two subjects were excluded due to technical errors caused by the scanner or goggles, and one subject was excluded due to a brain abnormality.

All studies were performed at the Semel Institute for Neuroscience & Human Behavior, and the Ahmanson-Lovelace Brain Mapping Center, University of California, Los Angeles. Written informed consent was obtained from all the subjects in accordance with the University of California, Los Angeles Human Subjects Protection Committee procedures.

MRI Data Acquisition

Images were acquired using a Siemens Allegra 3T whole brain MRI scanner at the Ahmanson-Lovelace Brain Mapping Center at University of California, Los Angeles. We collected blood oxygenation level-dependent functional echo-planar images using a pulse sequence with the following parameters: repetition time (TR), 2.5 seconds; echo time, 35 msec; flip angle, 90°; 28 slices; voxel dimensions, 3.1 × 3.1 × 3.0 mm; field of view, 200 mm; and matrix, 64 × 64. Slices were acquired with interleaved order. The data collected during the first two TRs were discarded to allow for T1 equilibration. A matched-bandwidth high-resolution anatomic scan coplanar to the echo-planar images was acquired for each subject with TR, 5 seconds; echo time, 33 msec; flip angle, 90°; 28 slices; voxel dimensions, 1.6 × 1.6 × 3.0 mm, field of view, 200 mm; and matrix, 128 × 128.

Cognitive Tasks During Scanning

During functional MR scanning, subjects performed either a novel Internet search task or a book reading task. Both MR scan runs included blocks of a control task of viewing nontext bar images. During each Internet task, subjects were instructed to obtain information on a specific topic, such as benefits of eating chocolate, mountains in the United States, planning a trip to the Galapagos, how to choose a car, walking for exercise, benefits of drinking coffee, or other topic areas of potential interest. To motivate subjects during the scanning session, they were told that they would be assessed for their knowledge of the topic after the scanning session. Subject groups did not differ significantly in the results of the knowledge-based assessments following the scanning sessions, indicating their equivalence in processing of task content (Table 1). Subjects pressed one of three response buttons to control the cursor for the simulated online search conditions within the MR scanner. For each stimulus block, subjects were first

TABLE 1. Characteristics of Subjects[a]

	Net Naïve (N = 12)	Net Savvy (N = 12)
Age (yr)	65.8 ± 4.7	62.4 ± 7.3
Education (yr)	17.2 ± 2.4	17.2 ± 2.4
Female, number (%)	11 (92)	9 (75)
Frequency of computer use[b]	1.8 ± 0.8	4.5 ± 1.2
Frequency of Internet use[b]	1.2 ± 0.4	4.5 ± 1.2
Self-rating of Internet expertise[c]	1.2 ± 0.1	3.6 ± 0.5
Questionnaire scores[d]		
Internet Task	79.2 ± 27.9	72.9 ± 29.1
Reading Task	75.0 ± 30.1	83.3 ± 19.5
Ethnicity		
African American	0	1
Asian	2	0
White	10	11

[a]Values are means ± standard deviations; significant group differences tested using two-sample *t* tests. No significant differences were found according to age (two-sample t (22) = 1.33, p >0.2), education (two-sample t (22) = −0.71, p >0.4); or sex (two-sample t (22) = −1.08, p >0.2) for Savvys compared with Naives. Significant group differences were found for frequency of computer use (two-sample t (22) = 6.60, p <0.0001), frequency of Internet use (two-sample t(22) = 9.38, p <0.0001), and self-rating of Internet expertise (two-sample t(22) = 17.6 , p <0.0001).

[b]Higher values on 1–5 scale indicate greater frequency: 1 = never or once a month; 2 = once or twice a week; 3 = four or five times a week; 4 = once a day; and 5 = several times a day.

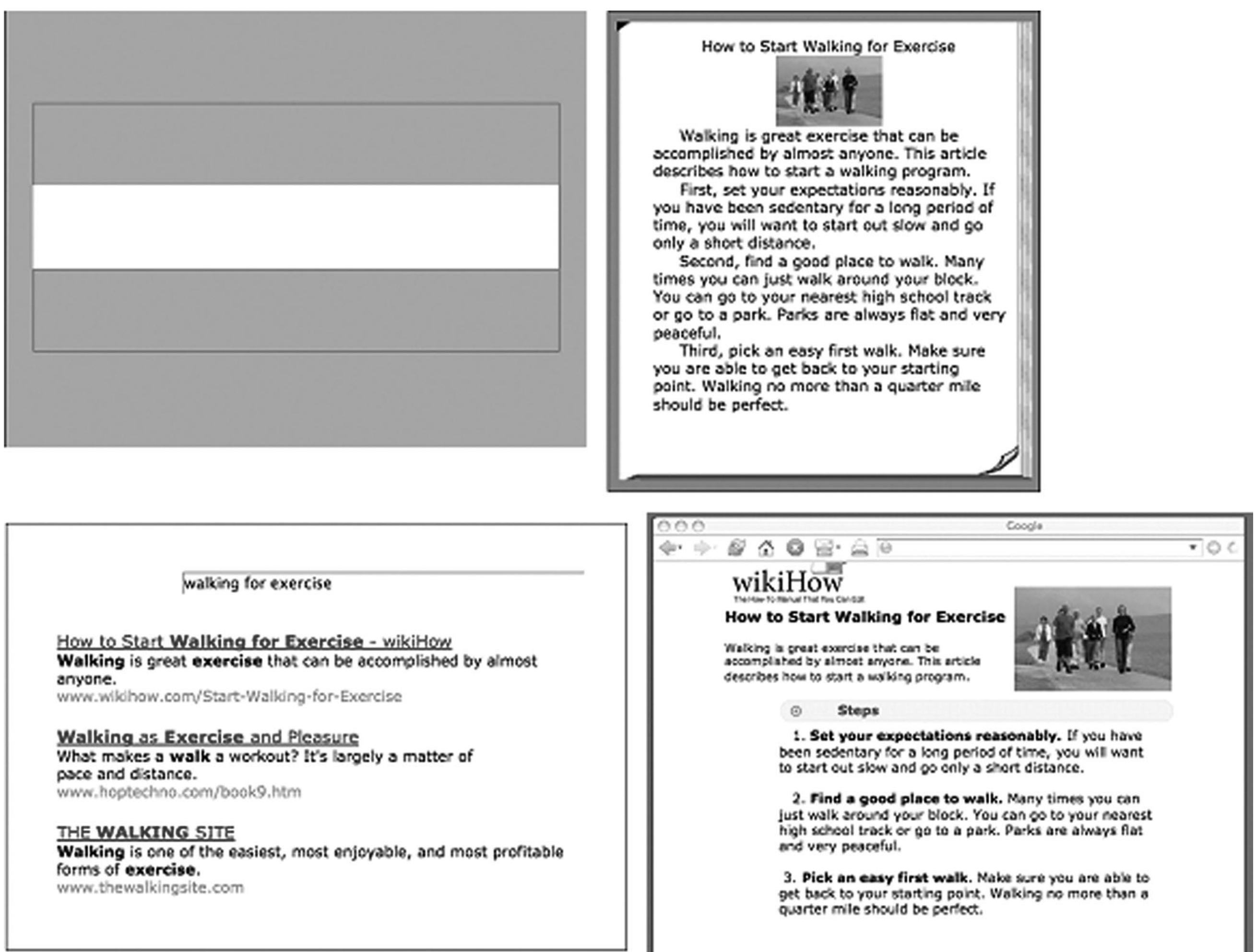
[c]Higher values on 1–4 scale indicate greater experience: 1 = none; 2 = minimal; 3 = moderate; and 4 = expert.

[d]Values are means ± standard deviations. No significant differences were found between groups for questionnaire scores for either the Internet or reading versions of the task. Internet task, Savvys compared with Naives: two-sample t (22) = −0.54, p = 0.60. Reading task, Savvys compared with Naives: two-sample t (22) = 0.80, p = 0.43.

given a topic they had to research, after which the search results would appear on the screen. In all trials, exactly three websites relevant to the topic appeared similarly to how they would on a search engine. Using the response buttons, subjects chose from three options presented on simulated web pages viewed through goggles (Fig. 1). This allowed the subject to press a button and "click" to advance to the next simulated web page, similar to a typical online search experience.

The text reading condition (Fig. 1) was designed to control for hand movement from operating the finger pad, visual and language stimulation from reading text and viewing photographs on web pages, and finger movement (subjects advanced the text page using the finger pad buttons). Subjects were also told that they would be assessed on the information they learned from reading the simulated text pages. Thus, the stimuli were matched for content across the Internet and reading conditions. There were two differences between tasks; first, in the Internet task, subjects chose which of the three websites they wanted to visit first, whereas in the reading condition the subjects were instructed to press a specific button to advance to a text page, and subjects pressed the corresponding button to reveal the text. Second, in the reading task, the text revealed after pressing the button and was laid out in a typical book format but with a picture on the "page," whereas in the Internet task, the identical text and

FIGURE 1. Examples of Task Pages Presented During Functional MRI Scanning: Nontext Bar Images (Upper Left); Text Page (Upper Right); Internet Page With Search Options (Lower Left); and Internet Information Page (Lower Right)



pictures were laid out like a typical website. Despite the differences in layout, the actual text and pictures were identical across conditions. The Internet layout included additional graphics, typical of actual Internet sites; however, pop-ups were not included (Fig. 1). Further, the stimuli were counterbalanced across subjects so that each topic appeared equally in the Internet and book formats. A nontext bar pressing task controlled for attention, decision making, and finger movement—subjects were asked to press the button corresponding to the highlighted bar images at regular intervals. Subjects performed separate runs of Internet and reading tasks. Each run was 4 minutes long, alternating six activation blocks with five 10-second blocks of the bar pressing control task. Each subject performed one run of the Internet task and one run of the reading task. Subjects were allowed 15 seconds for choosing a link and 27.5 seconds for reading the content of the web page. Similarly, subjects were allowed 15 seconds for reading the table of contents and 27.5 seconds for reading the book page. The order of task presentation was counterbalanced across subjects. Subjects were given instructions on the task before scanning and performed a short practice version of the task to confirm that they understood the task and could press buttons as instructed. The analysis combined the bulleted text and nonbulleted text for the Internet task, and combined the table of contents and the text page for the reading task. The order of tasks (Internet or book) was randomized across subjects.

Image Processing and Analysis

Image preprocessing and analysis were carried out using the Oxford, England, Centre for Functional MRI of the Brain (FMRIB)'s Software Library.[20] Spatial smoothing was applied using a full-width half-maximum Gaussian kernel of 5 mm. Preprocessing and analysis were run using fMRI Expert Analysis Tool version 5.91. To remove low-frequency artifacts, each functional run was temporally filtered using a high-pass cutoff of 100 seconds. For each functional run, motion correction was applied using 3-Da coregistration of each image to the middle image of the time series with Motion Correction using FMRIBs Linear Image Registration Tool.[21]

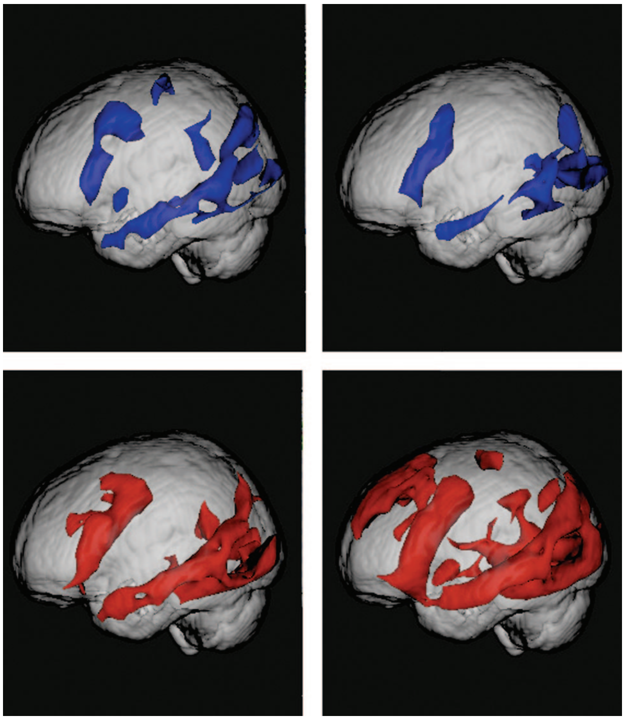
Subjects with head motion of more than 1.5 mm (one-half voxel) were not entered into further analysis. The remaining head motion profiles were further examined for evidence of remaining motion artifact post head motion correction. For these scans, an independent components analysis was carried out using the FMRIBs Multivariate Exploratory Linear Optimized Decomposition into Independent Components tool.[22] The spatial and temporal characteristics of each isolated component was examined, and components that were clearly related to motion or other sources of low- or high-frequency noise were removed. All statistical analyses were carried out both before and after denoising. The group statistical results, including the denoised dataset, did not differ qualitatively from those before denoising with Multivariate Exploratory Linear Optimized Decomposition into Independent Components.

Registration of the functional data followed a two-stage process using linear registration with FMRIBs Linear Registration Tool: each functional run was first registered to a higher resolution T2-weighted matched-bandwidth anatomic image of each subject (7 *df* affine transforms), and then to the Montreal, Quebec, Canada, Neurological Institute (MNI) 152 standard template anatomic image (12 *df* affine transforms).

Blood oxygenation level-dependent signal during the experimental versus control tasks was convolved with a canonical double-gamma hemodynamic response function, which models the rise and the following undershoot along with its temporal derivative. Statistical analysis was first performed on each subject's individual functional run using general linear modeling by FMRIBs Improved Linear Model. The second step analysis combined the task versus control comparisons for each group separately (Savvy and Naive subjects), using a random effects model by FMRIBs Local Analysis of Mixed Effects.[23,24] Resulting Z-statistic images were thresholded using cluster size determined by $Z > 2.3$ and a (corrected) cluster significance threshold of $p = 0.05$.[25] We then directly contrasted the Internet versus reading tasks using the experimental task versus bar pressing control results as a mask. This approach limits the number of multiple comparisons conducted to those demonstrated to be significant for the activation tasks, reducing the risk of false-positive errors. We limited this comparison to the single, one-tailed contrast of Internet > reading, because in the task versus control images, the Internet task appeared to have a greater magnitude of activation. The masked images were thresholded at a cluster p value of 0.05 corresponding to a cluster size threshold of $Z > 1.7$ (one tailed), corrected for multiple comparisons, and the between-condition comparisons using the masked regions of interest were conducted at $p < 0.05$. This analysis created maps that showed regions in which activation was significantly greater for the Internet compared with the reading task, separately for the Internet Naive and the Internet Savvy groups.

We used *t* tests conducted within FMRIBs Software Library. In this type of dataset, each voxel is tested (except as noted above, after masking), and all significant clusters of voxels are reported, after correction for multiple comparisons. The *df* for each voxel comparison task versus control within group is 11 and for between groups 22. For the comparison of the extent of activation in the major regional clusters in the Net Savvy group compared with the Net Naive group, we used the Kolmogorov-Smirnov test.

FIGURE 2. Activations for the Book Text Reading and Internet Searching Tasks in Comparison With the Baseline Nontext Bar Task (see Fig. 1)



Areas of activation are indicated in blue for the Net Naive group and in red for the Net Savvy group. Upper images: Internet Naive subjects while performing the reading task (left) and the Internet task (right). Lower images: Net Savvy subjects while performing the reading task (left) and the Internet task (right). *Z*-statistic images were thresholded using clusters determined by $Z > 2.3$ and a (corrected) cluster significance threshold of $p = 0.05$, $df = 11$.[25]

RESULTS

The Net Naive and Net Savvy subject groups were similar in age, sex, and prior educational achievement, and the groups differed significantly only in their prior technology experience (Table 1). On average, the Net Naive group rated their frequency of computer use in the once or twice a week range. Their average for Internet use frequency was in the never to once a month range and their self-rating of expertise was minimal to none. By contrast, the Net Savvy group rated their frequency of both computer and Internet use between once a day and several times a day. Their average self-rating of Internet expertise ranged between moderate to expert (Table 1).

During the text reading task, the Net Naive group showed significant MR signal activity, primarily in the left hemisphere, in frontal, temporal, and parietal (angular gyrus) regions, as well as in the visual cortex, hippocampus, and posterior cingulate (Fig. 2 and Tables 2 and 3). During the Internet search task, the Net Naive group showed a similar pattern of activation in these same regions, except for the posterior cingulate and hippocampus.

The Net Savvy group demonstrated significant MR signal activity in this same cluster of regions during the text reading task (Fig. 2). During the Internet search task, the Net Savvy group demonstrated significant activations in these same regions; however, additional significant activation was observed in the frontal pole, right anterior temporal cortex, the anterior and posterior cingulate, and the right and left hippocampus. The most striking finding was in the direct comparison of the Internet versus text reading tasks for the Net Naive and Net Savvy groups (Fig. 3)—the Net Savvy group demonstrated more than a twofold greater spatial extent of activation than did the Net Naive group (21,782 versus 8,646 total activated voxels) during the

TABLE 2. Clusters of Activation[a]

Book Task					
Savvy			Naïve		
Cluster Index	Cluster Size, Voxels	p	Cluster Index	Cluster Size, Voxels	p
5	5,282	<0.0001	7	2,750	<0.0001
4	2,734	<0.0001	6	1,660	<0.0001
3	421	<0.01	5	1,017	<0.0001
2	1,037	<0.0001	4	610	<0.001
1	528	<0.01	3	430	<0.01
			2	368	<0.01
			1	284	<0.05
Total activated voxels	10,002		Total activated voxels	7,119	
Internet Task					
5	19,845	0	5	2,750	<0.0001
4	636	<0.001	4	1,289	<0.0001
3	474	<0.01	3	985	<0.0001
2	427	<0.01	2	534	<0.01
1	400	<0.05	1	338	<0.05
Total activated voxels	21,782		Total activated voxels	8,646	

[a]Cluster Index refers to the numerical label assigned to each contiguous cluster of voxels exceeding a significance threshold $Z > 2.3$ and a (corrected) cluster significance threshold of $p = 0.05$.[25] p values are for the cluster sizes as a whole. All tests were *t* tests conducted within FSL ($df = 11$).

Internet task (Kolmogorov-Smirnov test statistic = 0.5, exact one-sided p value <0.05; Table 2).

DISCUSSION

To our knowledge, this is the first study to directly explore brain functional responses while volunteers engage in an Internet search task. In comparison with a task that simulates reading a book page of text, the pattern of activation was similar and spanned several regional clusters including frontal, temporal, occipital, cingulate, and parietal areas. The most striking finding of the present study was in the direct comparison of the Internet versus text reading tasks for the Net Naive and Net Savvy groups, which found that the Net Savvy group had more than a twofold greater spatial extent of activation than did the Net Naive group during the Internet task. People with prior Internet and computer experience demonstrated much greater extent of MR signal activity, particularly in brain regions controlling complex reasoning and decision making. Moreover, the particular neural circuits showing greatest increases were those that control mental processes critical to successful Internet search behavior.

Previous research has demonstrated altered brain functional patterns following repeated cognitive tasks. Studies of volunteers playing violent video games show both increases and decreases in signal, including activation of dorsal and deactivation of rostral anterior cingulate and amygdala.[12] Other studies have demonstrated decreased dorsal prefrontal activation during video game playing.[13] Recent studies have found computer-game play to activate brain regions associated with reward and addiction (e.g., orbitofrontal cortex) and decision making (e.g., dorsolateral prefrontal cortex).[27] Although video-game play resembles Internet searching in that it involves computer screen viewing and interactive responses to the information presented, these activities can differ considerably depending on the content and mental rewards associated with the tasks.

Haier et al.[19] found that playing the computer game Tetris each day for several months led to decreased cortical activity. Our group found that memory training, physical exercise, and other healthy aging life style behaviors led to decreases in dorsal prefrontal cortical metabolism after 2 weeks.[2] Such studies suggest that task repetition over time leads to greater cognitive efficiency reflected by lower activations following mental training.

The results of the present study demonstrated overall increases in regional activations that were associated with prior task experience. Clearly, neu-

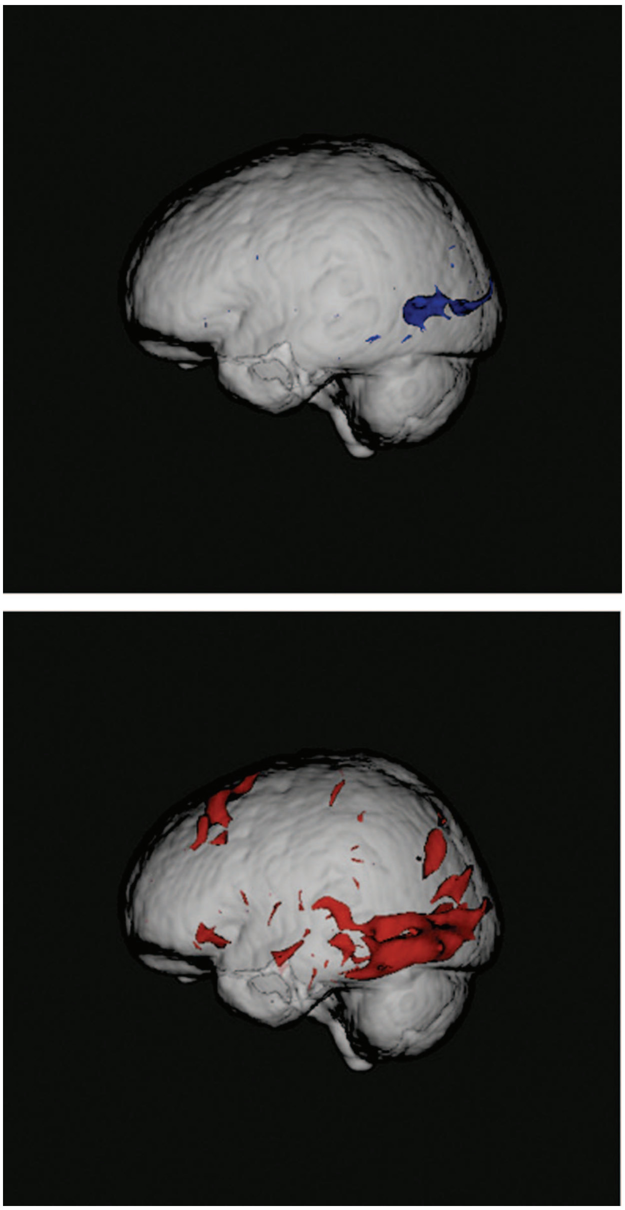
TABLE 3. Location and Magnitude of Activation Peaks[a]

			Book Task									
			Savvy					Naïve				
Location	BA	Hem	Cluster Index	Z_{max}	X	Y	Z	Cluster Index	Z_{max}	X	Y	Z
Frontal												
IFG ventral	45/47	L	4	3.7	−54	30	−6	6	3.91	−56	26	−4
IFG mid	44/45	L	4	4.83	−50	12	20	6	3.76	−46	18	18
	44	L	4	4.36	−46	28	12	6	4.08	−54	28	14
IFG dorsal	44/6	L	4	4.15	−46	0	32	6	3.84	−38	−2	32
MFG	9	L	4	3.81	−42	2	42	6	4.3	−46	10	44
IFG	44	R	1	3.52	50	30	14					
Temporal												
MTG ventral-anterior	21	L	5	3.41	−52	−8	−26	7	3.89	−56	0	−20
MTG mid	21	L	5	4.28	−62	−28	−6	7	3.69	−60	−16	−16
MTG posterior	21	L	5	4.45	−56	−38	−4	7	3.5	−60	−44	0
MTG ventral-anterior	21	R	3					1	3.45	60	−4	−20
Angular gyrus	39	L	5	3.67	−34	−74	32	7	3.64	−44	−66	34
Visual regions												
Fusiform gyrus-ant		L	5	4.31	−38	−50	−18	4	3.7	−36	−46	−20
Fusiform gyrus-post		L	5	3.7	−44	−64	−18	4	3.01	−44	−70	−12
Occipital lobe		L	3	3.85	−22	−102	−2	4	5.21	−14	−102	6
		R	3	4.21	26	−100	4	5	5.33	26	−90	−6
Hippocampus		L	5	3.68	−22	−30	−6	7	3.54	−20	−24	−20
Cingulate												
Posterior		L	2	3.51	−4	−56	16	3	3.08	−2	−60	14
Middle		R						2	3.51	8	−34	66
			Internet Task									
Frontal												
IFG ventral	45/47	L	5	4.05	−52	26	−6	4	3.97	−54	28	4
IFG mid	44/45	L	5	4.81	−56	20	20	4	3.89	−56	20	22
IFG dorsal	44/6	L	5	4.3	−46	8	22	4	3.6	−48	6	38
MFG	9	L	5	4.1	−42	2	40	4	3.28	−46	10	48
MFG anterior	10	L	5	3.76	−4	44	38					
SFG anterior	10	L	5	3.53	−10	14	64					
IFG	44	R	2	3.5	46	12	28					
Temporal												
MTG ventral-anterior	21	L	5	4.01	−56	0	−20	1	3.35	−56	10	−26
MTG mid	21	L	5	4.14	−56	−20	−8	1	3.29	−56	−16	−12
MTG posterior	21	L	5	5.21	−56	−38	−2	3	4.09	−56	−44	−2
MTG ventral-anterior	21	R	3	4.07	60	−6	−18					
Angular gyrus	39	L	5	4.16	−48	−70	20		3.37	48	−54	12
Visual Regions												
Fusiform gyrus-ant		L	5	4.4	−28	−36	−22	5	3.91	−44	−50	−18
Fusiform gyrus-post		L	5	4.6	−34	−54	−18	5	3.47	−52	−56	−14
		R	1	3.72	38	−48	−22					
Occipital lobe		L		3.89	−18	−102	−6	3	4.51	−14	−102	4
				3.36	−22	−80	48	2	4.2	−28	−74	48
		R	1	4.05	16	−92	−6	5	4.43	18	−102	10
		R	1	3.55	26	−86	40					
Hippocampus		L	5	3.79	−26	−24	−16					
		R	5	3.21	24	−18	−18					
Cingulate												
Posterior		L	5	4.06	−4	−56	10		3.35	−2	−54	12
		L		3.64	−4	−54	38					
Anterior		L	3	3.47	−6	26	34					
Precentral gyrus		R	4	3.5	12	−28	66					

Notes: BA: approximate Brodmann's region, based on the atlas of Talairach and Tournoux[26]; Hem: hemisphere; R: right, L: left; Z_{max}: the *Z*-score of the peak voxel of activation within the local cluster; *x, y, z*: reference coordinate system from the Montreal Neurological Institute (MNI) atlas instantiated within FSL; *x*: left-right, *y*: anterior-posterior; *z*: superior-inferior. IFG: inferior frontal gyrus; MFG: middle frontal gyrus; SFG: superior frontal gyrus; ITG: inferior temporal gyrus; MTG: middle temporal gyrus; ant: anterior, post: posterior.

[a]Cluster index refers to the numerical label assigned to each significant cluster of significantly activated voxels shown in Table 1.

FIGURE 3. Direct Comparisons of the Internet Task Versus Reading Task in Net Naive Group (Upper Image With Regions Activated in Blue) and Net Savvy Group (Lower Image With Regions Activated in Red)



The areas of activation are for the contrast of Internet task greater than reading task. These images used the masked ROI and are for the between-condition comparisons conducted at $p < 0.05$ ($df = 22$).

ral circuitry activations in response to specific mental tasks yield complex patterns. One explanation for the varied levels of regional activations is that novel and stimulating mental experiences initially lead to minimal activation before the individual grasps a strategy for solving a mental challenge. Once that insight is realized, specific regional circuits engage and show increase activity. Once the tasks become routine, repetitive, and without challenge, however, lower activity may be observed with functional imaging reflecting the efficiency of the neural response. Despite their prior computer experience, which might be associated with decreased activation reflecting cognitive efficiency, the Net Savvy subjects showed increased activation during the Internet search task, suggesting that Internet searching remains a novel and mentally stimulating process even after continued practice.

During the book reading task of the present study, a network of brain regions that control language and visual skills was activated, consistent with previous functional MRI studies performed during reading tasks.[28,29] The mental process of searching the Internet involves reading text so that it is not surprising that these regions were also activated during the Internet search task. However, Internet searching does involve additional cognitive tasks compared with reading a book page, particularly those related to making choices among several different selections describing further search information. Other functional MRI studies of the neural circuitry associated with decision making also have documented the involvement of prefrontal circuits, particularly the ventromedial prefrontal and cingulate cortices.[30,31]

Previous studies have demonstrated that cognitive training can have an immediate beneficial effect on task performance in people at any age,[2,32] and significant associations have been found between engaging in mentally stimulating activities and better cognitive performance.[1,32] Such findings have led to widespread acceptance of the view that engaging in mentally stimulating activities will maintain cognitive abilities and may prevent age-related cognitive decline. Unfortunately, few studies have found an interactive effect of age and mental activity on measures of cognitive functioning.[32] Despite the lack of empirical evidence supporting this “use it or lose it” hypothesis, many experts recommend that people should behave as although the hypothesis were true because there is no evidence that it is harmful and the activities are often enjoyable and contribute to a better quality of life. Our present results are encouraging that emerging computerized technologies designed to improve cognitive abilities and brain function may have physiologic effects and potential benefits for middle-aged and older adults. Controlled clinical trials assessing both neuropsychological and brain functional effects will be necessary to demonstrate the efficacy of these technologies.

Our findings indicate that Internet searching appears much more stimulating than reading. In fact, the Internet task demonstrated strongly enhanced activity in visual cortices when compared with the reading task in Internet Savvy subjects, although the actual visual stimuli were identical. This observation suggests that in the Internet task the subjects were attending far more to the visual information and demonstrating a richer sensory experience. These findings are consistent with previous neuroimaging studies showing that enhanced attention to visual stimuli increases activity in visual brain regions and is highly specific, i.e., enhanced attention to color activates regions controlling color perception, whereas enhanced attention to shape activates a different region.[33]

These findings also point to the sensitivity of brain neural circuits to common computer tasks such as searching online, and constant use of such technologies have the potential for negative brain and behavioral effects, including impaired attention and addiction.[34,35] Particular concern has been expressed about the vulnerability of a developing brain to such chronic exposure, which has led the American Academy of Pediatrics to recommend that parents limit the amount of screen time for children younger than 2 years of age when the brain is particularly malleable.[36] The results from the present study call for further research of both the potential positive and negative brain effects of such technologies on the more mature brain.

During the reading task, the Net Naive group demonstrated significant MR signal activity, particularly in the left hemisphere, in frontal, temporal, and parietal regions, as well as in the visual cortex, hippocampus, and posterior cingulate. It is possible that those subjects who spend less time using the Internet prefer to read, which might explain some of the neuronal network activation differences between groups. Data were not collected on the extent that subjects read for work or pleasure and is a limitation of the current study.

Several other methodological issues deserve comment. The subject sample was small and not representative of the general population. Sampling bias or measurement error or both could explain these results. Moreover, our finding that the two subject groups differed in the extent of brain activation during the Internet task does not prove a causal relationship between prior Internet experience and neural circuitry response. It is possible that some other factor could explain why individuals who choose to avoid using computers demonstrate a different activation response. The decision to avoid technology may reflect a pattern of other life style choices that could explain our findings. Other research has shown that physical activity levels and dietary habits can contribute to brain health and function,[2] and it is possible that individuals who choose to use or avoid technology have different patterns of other life style choices that could influence brain function. Subjects were able to successfully complete the tasks and had no history of cognitive impairment or major neuropsychiatric or medical illnesses, but it is also possible that unrecognized incipient cognitive neuropsychiatric conditions may have influenced these results.

Despite such limitations, our findings point to an association between routine Internet searching and neural circuitry activation in middle-aged and older adults. Further study will elucidate both the potential positive and negative influences of these technologies on the aging brain and the extent to which they may engage important cognitive circuits controlling decision making and complex reasoning.

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