Neuroscience 335 (2016) 82–90

SHORT-TERM INTERNET-SEARCH PRACTICING MODULATES BRAIN ACTIVITY DURING RECOLLECTION

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Abstract—Internet-searching behaviors may change ways in which we find, store and consider information. In this study, we tested the effect of short-term Internet-search practicing on recollection processes. Fifty-nine human subjects with valid data (Experimental group, 43; Control group, 16) completed procedures involving a pre-test, 6 days of practicing, and a post-test. Behavioral and imaging results were obtained and within- and between-group comparisons were made at pre-test and post-test times. With respect to behavioral performance, six days of practicing was associated with improved behavioral performance during Internet searching: subjects in the experimental group showed shorter response times (RTs) and similar accuracy rates during recollection at post-test as compared to pre-test. During imaging and as compared to pre-test data, subjects in the experimental group showed during post-test recall relatively decreased brain activations bilaterally in the middle frontal and temporal gyri. Such findings were not observed in the control group. The findings suggest that six days of practicing Internet searching may improve the efficiency of Internet searching without influencing the accuracy of recollection, with neuroimaging results implicating cortical regions involved in long-term memory and executive processing.

Key words: internet search, short-term training, working memory, long-term memory.

INTRODUCTION

More than 100 years ago, Friedrich W. Nietzsche (1844–1900) noticed that the equipment he used in writing (a typewriter) contributed to the formation of his thoughts (Nicholas, 2011). This observation raises question regarding whether and how modern tools may modify ways of thinking. The Internet search engine, arguably one of the most important inventions in the past few decades, has become an indispensable tool for many individuals. It has changed ways of finding and storing information by making much information readily available through the typing of a few words and by representing an 'external memory source' that may be easily accessed.

The current environment has thus arguably lessened the importance of utilizing strategies and effort to remember things as one may instead 'Google' for information. It has been proposed that people use Internet search engines as 'external memory drives', with individuals becoming better at remembering where information is stored than in recalling the information itself, which has been termed the 'Google effect' (Sparrow et al., 2011). This effect appears related to the transactive memory theory (Wegner, 1995) which states that people divide the labor of remembering certain types of shared information if they know someone who (or something that) knows that information. We previously found that Internet-based searching facilitated the information-acquisition process; however, this process may have been performed more hastily and may have been more prone to difficulties in recollection (Dong and Potenza, 2015). Booth & Smith found that when participants were using a search engine, as opposed to when seeking and remembering information through other mechanisms, they used more search terms, stayed online longer, and found more sources of information (Booth and Smith, 2009). We previously found that people showed less confidence in recalling information learned through Internet searching and that recent Internet searching may promote motivations to use the Internet for searching (Dong and Potenza, 2015).

Scholars have postulated that the popularity of Internet searching may lead individuals to lose the ability (or not develop the ability) to process and store information effectively, and that brains are being 'rewired' through these uses of digital technologies (Nicholas, 2011). Nicholas and colleagues found that the 'Google generation' (participants born after 1993) demonstrated weaker working memory and less confidence about the answers they provided than did older

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Abbreviations: DLPFC, dorsolateral prefrontal cortex; fMRI, Functional magnetic resonance imaging; FWE, Family-wise error; GLM, general linear model; MTG, middle temporal gyrus; ROIs, regions of interests; RTs, response times.

http://dx.doi.org/10.1016/j.neuroscience.2016.08.028
0306-4522/

participants (Nicholas et al., 2011). At the same time, the younger individuals performed searches more rapidly and spent less time on individual questions. While important, such cross-sectional studies are limited with respect to investigating possible 'cause and effect' influences. As such, it is not known whether such observations are related to the influences of specific environmental conditions. Thus, longitudinal studies might help inform how Internet use may alter behaviors and brain function. Short-term training (5 days) of subjects aged 55–75 years indicated that, 'in middle-aged and older adults, prior experience with Internet searching was related to brain responsiveness in neural circuits involved in decision-making and complex reasoning' (Small et al., 2009). More longitudinal studies are needed to explore possible effects of Internet searching on brain and behavior.

The brain is the source of behavior, but in turn it is modified by the behaviors it produces (Zatorre et al., 2012). This dynamic loop between behavior and brain function is at the root of the neural basis of cognition, learning and plasticity. Short-term training or practicing may modify brain activities related to specific functions. Short-term meditation may modulate brain activity (Ding et al., 2015), white-matter connectivity (Tang et al., 2012) and default-mode-network function (Brewer et al., 2011). Seven days of n-back practicing may alter neural responses in working-memory-related brain regions (Buschkuehl et al., 2014). Working-memory training may increase the neural efficiency and capacity in older (Heinzel et al., 2014) and younger (Langer et al., 2013) adults and lower prefrontal cortical activation during thinking tasks (Vartanian et al., 2013). These studies suggest that short-term training or practicing may modify cognitive function and be reflected in neural activities. Internet searching involves practicing and may influence how people approach gathering and storing information. Despite accumulating behavioral work, knowledge about the neural mechanisms underlying training effects relating to Internet use is scarce. Thus, this study sought to explore the possible effects of short-term Internet-search practicing on brain function when encountering information learned through Internet searching.

The concept that brain function can be modified by experience, while not new, has until recently been challenging to investigate directly. Functional magnetic resonance imaging (fMRI) facilitates such investigations and may provide insight into how training or practicing may influence brain function. Thus, in the present study, we used fMRI to identify differences in brain activation before and after Internet-search practicing. We hypothesized that Internet-search practicing would improve the efficiency in a searching-remembering task and that these changes would be reflected in brain activations in regions previously implicated in working memory and/or executive processes (Vartanian et al., 2013; Buschkuehl et al., 2014). Given that our previous studies focusing on the comparison between two different groups showed that people using Internet search as their tools in finding and remembering new information showed lower brain activations in declarative-memory-related brain regions (Dong and Potenza, 2015), such as in the middle temporal gyrus (MTG) and along the ventral stream (Knutson et al., 2012; Jeneson and Squire, 2012a), we hypothesized involvement of these regions. In addition, given data suggesting that individuals appear better at remembering where information was stored ('where information') than in recalling the information itself ('what information') (Sparrow et al., 2011), we hypothesized the practicing process would make people less dependent on long-term declarative memory (lower brain activations in regions along the ventral stream) and more dependent on 'where-related' brain regions (higher brain activations in regions along the dorsal stream).

METHODS

Participants

The experiment conforms to The Code of Ethics of the World Medical Association (Declaration of Helsinki). The Human Investigations Committee of Zhejiang Normal University approved this research. Sixty-six university students were recruited as subjects through advertisements (48 in the experimental group, 18 in the control group), 59 of whom completed the whole study (43 in the experimental group (male, 22; female, 20; age: 21.4 ± 1.2 years), 16 in the control group (male 7, female, 9; age: 21.2 ± 0.5 years)). Before entry into the study, all participants provided written informed consent. All participants were free of psychiatric disorders (including major depression, anxiety disorders, schizophrenia, and substance dependence disorders) as assessed by the MINI (Lecrubier et al., 1997). All participants were medication-free and were instructed not to use any substances, including coffee, on the day of scanning.

To obtain information regarding Internet-searching behaviors, all subjects were assessed using an Internet-search-use questionnaire (Dong and Potenza, 2015). The responses to the questionnaire showed that all subjects were familiar with Internet searching and used the Internet regularly for such purposes. Participants were divided into one of two groups randomly. No difference was found in Internet-search-use behaviors between the two groups (experimental group, 36.4 ± 2.4; control group, 34.5 ± 1.3; $t = 0.48$, $p > 0.05$). Given financial limitations, we studied a relatively small number of subjects in the control condition (16 subjects with usable fMRI data) in the current study. However, this number has been described as being sufficient for fMRI studies (Huettel et al., 2004).

EXPERIMENTAL PROCEDURES

The experiment consisted of three steps: pre-test, six days of practicing, and post-test (Fig. 1A).

The task used in pre- and post-practicing scans

To avoid possible repetition effects, the fMRI tasks used in pre- and post-practicing times are similar but differ in content. We designed two versions of the task with