RUNNING TITLE: Internet-search practicing and memory

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 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.

Keywords: 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 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 ([Buschkuhl 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 ([Buschkuehl et al., 2014](#); [Vartanian et al., 2013](#)). 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 and along the ventral stream ([Jeneson and Squire, 2012a](#); [Knutson et al., 2012](#)), 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 ([Figure 1A](#)).

Insert Figure 1 about here

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 different items (versions A, B). Half of the participants participated in an 'A-B' sequence, and the other half received a 'B-A' sequence in their pre- and post-practicing scans. Before the formal scan, participants were asked to find the answers to 40 questions through an Internet search engine and remember the answers in an hour. The questions were shown on a computer screen in PDF format. Participants were asked to find the answers to questions and remember them without taking notes. This approach was used to avoid making the remembering process too simple and to promote memory generation and recall processes without the benefits of note-taking or notes. All of the 40 questions used in this process were uncommon topics, and this approach was taken to avoid potential effects of participants' previous knowledge. In addition, participants were asked to identify questions to which they already knew the answers before the remembering step. These items were excluded from further analysis (on average 1.34 ± 0.37 items/subject). After subjects finished the remembering process, participants were asked to perform a 5-minute distraction task (continuously subtract 4 from 99) and complete a

questionnaire (The UCLA loneliness questionnaire, taking about 5 minutes to complete). This approach was used to avoid participants' recitation during the waiting period. After the completion of the distraction task, subjects entered the scanning room and prepared for fMRI scanning. Approximately 10 minutes elapsed between the end of the last distraction task and the onset of scanning.

The fMRI task was described in our previous study ([Dong and Potenza, 2015](#)) and was performed as follows. In the scanner, participants were asked to perform a 'recall and recognition' task ([Figure 1B](#)). In one trial, a fixation was presented first for 500ms, then one question was presented and then participants were asked to respond 'remember' or 'forget' via button press. After key pressing, a black screen appeared for (4000 - the response time) ms. Thereafter, another jittered black screen was presented for 500 to 2500ms. The recognition stage followed (same question as in the recall stage). During the recognition stage, participants were asked to choose one answer from the listed answers. This stage lasted for up to 2000ms (awaiting a button press), which was followed by a black screen with a jittered interval ranging from 1500ms to 3500ms ([Figure 1B](#)). In the current study, we focused on the recollection stage. These procedures, including stimuli presentation and behavioral data collection, were performed using E-prime software (Psychology Software Tools, Inc.).

To motivate participants to respond accurately, they were told that they would be paid a guaranteed 50 Yuan (≈ 8 US\$) for participation and an additional 0–40 Yuan

based on their task performance. Specifically, if they responded 'remember' in the recall stage and chose the correct answer in the 'recognition' stage, they would gain an extra 1 Yuan for each trial. On the contrary, if they responded 'remember' in the 'recall' stage and chose the incorrect answer in the 'recognition' stage, they would lose 1 Yuan. The other responses were not be rewarded or punished.

The practicing process

After the pre-test, the practicing process started on the immediately following day and lasted for six days. Following the six days of practicing, the post-test occurred on the immediately following day. Thus, the time between pre-test and practicing was one day, as was the time between practicing and post-test. Subjects practiced for more than one hour per day over a period of 6 consecutive days. In the experimental group, subjects were asked to finish one of six search tasks, randomly and with no repetition. Each search task consisted of 80 fill-in-the-blank items that required subjects to seek answers through the use of an Internet search engine. Participants were paid up to 20 Chinese Yuan per day for their participation. To increase their motivation, subjects were informed that they would be paid according to their performance ($20 * \text{accuracy rates (\%)}$). If they finish the work seriously and the accuracy rates are higher than 80%, then they passed the training. According to these criteria, all subjects passed their trainings.

In the control group, subjects were asked to use the computer for about 1.5 hours. No limitations (except doing online searches) were made with respect to their online behaviors except that they were instructed to do one thing all the time during

these six training periods (do one thing systematically); for example, read the news or play online games. Additionally, they were not allowed to do one thing consecutively; for example, if they played online games on the first day, it would not be allowed for them to play online games on the second day, although they could on the third day, for example. All of these procedures took place in quiet and comfortable rooms near the MRI scanner at the MRI center.

fMRI data collection

Structural images were collected using a T1-weighted three-dimensional spoiled gradient-recalled sequence covering the whole brain (176 slices, repetition time=1700 ms, echo time TE=3.93 ms, slice thickness=1.0 mm, skip=0 mm, flip angle=15, inversion time=1100ms, field of view=240*240mm, in-plane resolution=256*256). Functional MRI was performed on a 3T scanner (Siemens Trio) with a gradient-echo EPI T2* weighted sensitive pulse sequence in 33 slices (interleaved sequence, 3mm thickness, TR=2000ms, TE=30ms, flip angle 90°, field of view 220x220 mm², matrix 64x64) (Dong et al., 2013; Dong et al., in press). Stimuli were presented using an Invivo synchronous system (Invivo Company, www.invivocorp.com) through a screen in the head coil, enabling participants to view the stimuli. The whole scanning process lasted for about 20 minutes (task, 10 minutes; T1, 7 minutes; setting parameters, 3 minutes).

Data pre-processing

The functional data were analyzed using SPM8 (<http://www.fil.ion.ucl.ac.uk/spm>), and Neuroelf (<http://neuroelf.net>), as described previously (DeVito et al., 2012; Krishnan-Sarin et al., 2013). Images were slice-timed, reoriented, and realigned to the first volume, with T1-co-registered volumes used to correct for head movements. Images were then normalized to MNI space and spatially smoothed using a 6mm FWHM Gaussian kernel. A general linear model (GLM) was applied to identify BOLD activation in relation to brain activities. Different types of trials were separately convolved with a canonical hemodynamic response function to form task regressors (involving four types of trials: remember-correct; remember-incorrect; forget-correct; forget-incorrect). The duration of each trial was 4000ms. The GLMs included a constant term per run. Six head-movement parameters derived from the realignment stage were included to exclude motion-related variances (subjects were excluded from further analysis if they exceeded movement criteria of 2mm or 2 degrees between TRs). A GLM approach was used to identify voxels that were significantly activated for each event during the recollection stage. Remember-correct trials, referring to those trials in which participants answered 'remember' in the recollection stage and chose the correct answer in the recognition stage, were included in the current analyses.

Post-test versus pre-test comparisons

Voxel-wise repeated-measures ANOVAs (group* pre_post) were administered to find the difference between pre- and post-tests across groups. All imaging results were corrected using AlphaSim Family-wise error (FWE)

(<http://www.fmrib.ox.ac.uk/analysis/techrep/tr00df1/tr00df1/node6.html>).

Significant clusters (FWE-corrected, $P < 0.01$) were thresholded at $P < 0.01$, two-tailed, with an extent of at least 125 voxels.

Correlation analyses between behavioral performance and brain responses

To investigate our hypotheses, we first compared the brain activation between pre- and post-tests and took the surviving clusters as regions of interests (ROIs) for further analysis. For each ROI, a representative BOLD beta value was obtained by averaging the signal of all the voxels within the ROI. In current study, we performed the correlations between brain activations in frontal areas and in the middle temporal gyrus (see the results and discussion below).

Results

No between-group difference was observed in behavioral performance and imaging results at the pre-test stage, as elaborated below.

Practicing and behavioral performance

During the six days of practicing, the time that subjects took to complete the searching task become increasingly shorter in the experimental group. A significant difference was observed with respect to the times spent searching between the first and sixth days ($t_{42}=7.415$, $p=0.000$, *partial* $\eta^2=0.840$) (Figure 2A).

With respect to response times (RTs), no difference was found at pre-test across groups ($t=0.33, p=0.63$). The experimental group demonstrated shorter RTs during recollection at post-test relative to pre-test [$t_{42}=2.35, p=0.024, \text{partial } \eta^2 =0.98$] (Figure 2B). No measurable behavioral differences were found in the control group when comparing RTs at post-test versus pre-test (Post: 1834 ± 187.40 ms; Pre: 1817 ± 178.76 ms) [$t_{11}=0.83, p=0.78, \text{partial } \eta^2 =0.015$].

The accuracy rate was derived by dividing the number of trials that were selected as remembered in the recollection stage and answered correctly in the recognition stage by the total number of trials. With respect to accuracy rates, no between-group difference was found at pre-test ($t=0.28, p=0.73$). In the experimental group, the accuracy rates did not change from pre-training test to post-training test [$t_{42}=0.49, p=0.49, \text{partial } \eta^2 =0.012$] (Figure 2C). Similar results were observed in the control group (Post: 0.73 ± 0.023 ; Pre: 0.74 ± 0.011) [$t_{42}=0.62, p=0.39, \text{partial } \eta^2 =0.028$].

Insert Figure 2 about here

Imaging Results

The ANOVA results showed that no brain regions showed group differences at the pre-test stage. No difference was observed in the control group when comparing the post-test to pre-test fMRI data. In the experimental group, when comparing the post-test to pre-test data, subjects showed decreased brain activation bilaterally in the middle frontal cortex (predominately in the dorsolateral prefrontal cortex - DLPFC), bilateral middle temporal gyrus (MTG), and right caudate when recalling

the information they had just searched and remembered through use of the Internet (Figure 3A). Extracted beta-weights showed that the difference was related to decreased brain activations at post-testing versus pre-testing (Figure 3B1, B2). Additionally, changes in the cingulate gyrus were observed (Table 1).

Insert Table 1 about Here

Insert Figure 3 about here

Discussion

Practicing improved performance of Internet-searching behaviors

As expected, the practicing in the experimental group was associated with improved performance on the Internet-search task. The experimental group used increasingly less time with increased practicing, suggesting that the speed of performance improved over time (Figure 2A). At the same time, the experimental group showed shorter RTs but similar accuracy rates in the recollection task in the comparison of post-test to pre-test measures. In contrast, there were no measurable improvements in the comparison group from pre- to post-testing. These results suggest that the six days of practicing improved the efficiency of individuals' online searching abilities.

As compared to pre-test fMRI data, subjects in the experimental group at post-test showed decreased brain activations in the frontal cortex, covering the bilateral DLPFC and extending to the orbitofrontal cortex. Multiple neuropsychological findings implicate the prefrontal cortex in working-memory processes (Turriziani et al., 2008; Wang et al., 2015). These frontal brain regions contribute to executive

functioning, information processing, and working memory, especially during free recall (Rushworth et al., 2004; Talati and Hirsch, 2005). Studies involving multiple patient groups have shown that working-memory performance is associated with medial frontal cortical function (Amici et al., 2007; Luerding et al., 2008). The reduced activity in this area correlates to poor performance on working memory tasks (Barbey et al., 2013). Frontal brain regions may also contribute to decision-making possibly independent of learning and memory (Dong and Potenza, 2016; Kohno et al., 2014; Stout et al., 2004), a process that relies in part on frontal cortical function and may contribute to the current findings relating to Internet searching. The caudate has also been related to learning and working memory (Dong et al., in press) and decision-making (Kohno et al., 2014), and it contributes importantly to dorsal-prefrontal cortex subcortical circuitry (Dong et al., 2015; Foerde and Shohamy, 2011; Grahn et al., 2009). Functional imaging has shown activation of this circuitry during working-memory and decision-making tasks in primates and human subjects (Hannan et al., 2010; Levitt et al., 2002) and in rats (McGaugh, 2004). According to the features of the task and the functions of these brain regions, it is likely that the practicing process improved subjects' performance through facilitating frontal cortical functioning during searching: it improved RTs while maintaining accuracy, and this was observed in conjunction with less recruitment of frontal cortical regions bilaterally.

Practicing may make people less dependent on activation of the middle temporal gyrus, a region implicated in long-term memory processes

Another identified brain region identified in the post-/pre-test comparison in the experimental group was the middle temporal gyrus (MTG), which is thought to be an important region for long-term memory processes. The MTG has been implicated in encoding declarative long-term memory, with declarative memory referring to all memories that are consciously available ([Axmacher et al., 2008](#); [Barense et al., 2005](#); [Cohen and Stackman Jr, 2014](#); [Jeneson and Squire, 2012b](#); [Simons and Spiers, 2003](#)). Declarative memory for rapidly learned, novel associations depends on MTG function ([Knutson et al., 2012](#); [Smith et al., 2014](#)). Patients with damage to the MTG were found to perform poorly on explicit learning tests ([Meulemans and Van der Linden, 2003](#)) and may show impairment in remembering visual information across delays as short as a few seconds ([Knutson et al., 2012](#)). The MTG is at the end of the ventral stream, which has been described as the ‘what’ stream. This stream travels from primary visual cortex to the temporal cortex and is involved in object identification and recognition ([Goodale and Milner, 1992](#); [Goodale et al., 1991](#); [Mishkin and Ungerleider, 1982](#)). Thus, in the current study, the lower brain activations in MTG at post-testing in the experimental group suggest subjects may exhibit following practicing less recruitment of regions involved in long-term memory processes. It is possible that Internet-search practicing made people more skilled in searching, while at the same time they relied less on their long-term memory.

This result, to some degree, is in line with Sparrow’s conclusion that people who use Internet search engines are better at remembering where information is stored than

at remembering the information itself (Sparrow et al., 2011). It is also consistent with our previous study that people who use Internet searching as their learning tool show lower brain activations along the ventral stream during recollection, as compared to people using Encyclopedia as their learning tool (Dong and Potenza, 2015). Inconsistent with our *a priori* hypothesis, no brain regions along the dorsal stream were identified. The dorsal stream, also known as the ‘where’ stream, has been implicated in the identification of the location of objects. The current results suggest that ‘where’ information on the Internet may be more abstract, and this notion is consistent with conceptualizations of the Internet as less of a ‘location’ given its virtual nature than a spatial position in the real world. This notion is also consistent with prior findings on Internet searching (Dong and Potenza, 2015).

The behavioral data also support the notion of practicing improving efficiency: subjects in the experimental group showed shorter RTs and similar accuracy at post-testing during recollection. The greater rapidity in searching, in conjunction with similar accuracy, raises the possibility that Internet-search practicing may promote efficient information gathering with less reliance on mental functioning involved in long-term memory processes. Another brain region implicated in the current study is the posterior cingulate, a region which is a component of the default-mode (Ding et al., 2014) and attentional (Kucyi et al., 2016) networks. The extent to which the changes in activity of the posterior cingulate relate to specific

cognitive functions like attention that is paid to specific aspects of recollection warrants additional investigation.

Limitations

Several limitations exist. First, given financial limitations, fewer participants were included in the control group (16 subjects with usable data), leading both to an imbalance in subject numbers in the experimental and control groups and a relatively small number of individuals in the control group. Second, given the prevalence of Internet searching, all subjects were familiar with this activity. Additionally, subjects' behaviors during the practice days were not monitored outside of the times of the experimental and control conditions, and subjects may have engaged to varying degrees in Internet searching outside of the study. Both of these factors may have influenced practicing effects. Nonetheless, the findings provide a foundation for addressing important questions regarding the potential influences of Internet on behavioral performance and brain function. Future studies involving different groups (e.g., children and adolescents) would help understand how the widespread use of the Internet may relate to health and functioning during development and across the lifespan.

Contributors

Guangheng Dong designed the task and wrote the first draft of the manuscript. Marc Potenza contributed in editing, interpretation and revision processes. All authors

contributed to and have approved the final manuscript.

Competing Interests

The authors declared that no competing interests exist.

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Figure Legends:

Figure 1. The task and timeline of one trial at pre- and post-testing

(A) The whole task consists of three steps: pre-test, six-days of practicing, and post-test. (B) The timeline of one trial at pre- and post-testing.

Figure 2. Behavioral performance in the experimental group

(A) The time participants used in the six training days. (B) The response time during the recollection stage at pre- and post-testing. (C) The accuracy rates during the recollection stage at pre- and post-testing.

Figure 3. Imaging results when comparing post-testing to pre-testing in the experimental group

(A) Subjects showed decreased brain activations at post-testing relative to pre-testing. (B) Extracted beta-weights in the bilateral middle frontal gyrus (mean value) and bilateral middle temporal gyrus (mean value) at pre- and post-testing.

Table 1: Regional brain activity changes in the recollection stage when comparing post-test to pre-test fMRI data

	x, y, z ^a	x, y, z ^a	Cluster size ^b	Region ^c	Brodmann's Area
1	21, 30, 36	-5.349	729	R Middle Frontal Gyrus	8, 9, 45
2	-45, -78, 30	-4.978	914	L Middle Temporal Gyrus L Superior Occipital Gyrus	21, 7
3	-18, 57, 36	-5.029	1459	L Middle Frontal Gyrus L Superior Frontal Gyrus	8, 9, 46, 10
4	66, -36, -9	-4.397	506	R Middle Temporal Gyrus	21
5	3, -42, 30	-4.278	255	R Cingulate Gyrus	31
6	27, -12, 21	-4.130	259	R Caudate	

^a Peak MNI Coordinates.

^b Number of voxels. We first identified clusters of contiguous voxels significant at an uncorrected threshold $p < 0.01$, as is also used for display purposes in the figures. We then tested these clusters for cluster-level FWE correction $p < 0.01$ and the AlphaSim estimation indicated that clusters with 125 contiguous voxels would achieve an effective FWE threshold $p < 0.01$. Voxel size = $3 \times 3 \times 3$.

^c The brain regions were referenced to the software Xjview (<http://www.alivelearn.net/xjview8>) and verified through comparisons with a brain atlas.

B1

B2