Functional Neuroimaging Investigation of the Neural Mechanisms for Successful Feeling-of-Knowing Judgments

Ronit Greenberg

Georgia Institute of Technology

Senior Thesis

Advisor: Chris Hertzog, PhD

Reviewers: Chris Hertzog, PhD, Eric Schumacher, PhD

Abstract

A feeling-of-knowing (FOK) is a sense of knowing that an item would be recognizable if seen again later, despite one's current inability to recall that item from memory. An FOK judgment occurs after a memory search and is a prediction of future recognition. The current study aimed to: (1) determine the brain regions involved in successful (accurate) and unsuccessful (inaccurate) episodic FOKs; (2) replicate the ability of FOKs to predict recognition outcomes and recollection/know (R/K) judgments; (3) explore the different effects of familiarity and recollection on high and low FOKs; and (4) determine the effect of overlearning on FOKs and their ability to predict recognition and R/K outcomes. Nine younger adults (ages 18-26) participated in 2 experimental sessions (encoding and testing), separated by a 48-hour delay (n = 4 for fMRI data). The amount of exposure to the studied items (1 versus 3 presentations) was manipulated. Statistically significant results include (1) a repetition effect such that the words that were repeated during encoding have higher mean recall, mean FOK rating, mean recognition accuracy, and mean R/K than those words presented only once; (2) activity in the ventral lateral prefrontal cortex (PFC) for successful or accurate FOKs; (3) activity in the anterior PFC for accurate high FOKs; and (4) activity in the PFC and anterior cingulate for correctly recognized and remembered items. In future, additional participants are necessary to conduct further and more detailed analyses.

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The term metacognition generally incorporates knowledge and cognitive regulation (Souchay, Isingrini, Clarys, & Taconnat, 2004). Metacognitive knowledge is defined as knowledge about one's own cognitive abilities, whereas metacognitive regulation pertains to processes that coordinate cognition (Souchay et al., 2004). Two types of regulation processes are monitoring, in which one's own knowledge and performance play a large role, and control, in which behavior is self-regulated (Nelson & Narens, 1990). Metamemory refers to knowledge about one's own memory processes (Perrotin, Isingrini, Souchay, Clarys, & Taconnat, 2006).

One such metamemory judgment is a feeling-of-knowing (FOK). An FOK is a sense of knowing that an item would be recognizable if seen again later, despite the inability to recall that item from memory. An FOK judgment occurs after a memory search and is a prediction of future recognition. FOK accuracy or success is defined as the degree to which FOK judgments predict recognition performance, and this degree of relatedness is usually determined using non-parametric gamma correlations (Nelson, 1984). The gamma correlation acts as an index of the rank order agreement of FOKs with recognition. There are two types of FOK accuracy: absolute accuracy, or calibration, and relative accuracy, or resolution. Calibration refers to the degree to which the mean level of FOKs corresponds to the mean level of recognition accuracy, whereas resolution is the degree to which high FOKs correspond to successful recognition and low FOKs correspond to unsuccessful recognition (Hertzog & Hultsch, 2000).

FOK judgments can be generated for both semantic and episodic memory tasks. Episodic memory is defined as knowledge pertaining to specific events, times, and places that are personally experienced (Perrotin et al., 2006), like an internal diary, whereas semantic memory refers to facts and general knowledge about the world. Typically, retrieval of episodic memory occurs via conscious contextual cues as opposed to the conceptual cues used to retrieve semantic memories. An FOK judgment can require participants to predict future recognition of unrecalled items either from semantic, or long-term, memory (Hart, 1965; Nelson & Narens, 1990) or from recently learned information in episodic memory (Schacter, 1983). FOK judgments, as reported by Metcalfe, Schwartz, and Joaquim (1993), are rated higher with increased cue familiarity, but are not affected by target memorability.

It has also been reported that FOKs are sensitive to manipulations of familiarity (Reder, 1987). FOKs are not only accurate in prediction of later recognition but are correlated with future states of awareness about recognition judgments as well, such as remember/know (R/K) judgments (Hicks & Marsh, 2002). Any information available during the production of an FOK may also be accessed while making a recognition judgment.

One hypothesis regarding FOK judgments suggests that these metamemory judgments are based on “trace-access” to the information stored in memory (Hart, 1965). FOKs would then result from partial access to a memory trace despite the failure of a retrieval attempt for that memory. There are two prominent more recent hypotheses in the FOK literature: the cue-familiarity (Metcalfe et al., 1993; Reder, 1987) and accessibility (Koriat, 1993) accounts. Koriat and Levy-Sadot (2001) suggest a model that combines these two accounts, in which accurate memory judgments require a process that begins with cue-familiarity and ends with an accessibility assessment. A quick evaluation of the familiarity or novelty of the presented cue thus provides the basis for FOK judgments. If the cue is sufficiently familiar, the FOK judgment will be based on a retrieval attempt and hence the degree of accessibility of relevant information to the target. If the cue is deemed unfamiliar, then the item is discounted and no accessibility assessment occurs. Koriat's studies (1993; 1995) show that FOK magnitude increases with increased information accessibility, regardless of the accuracy of this information.

Perrotin et al. (2008) suggest that, within this Koriat and Levy-Sadot (2001) FOK model, executive functioning is critical in the accessibility assessment stage rather than in the initial cue-familiarity stage, since familiarity judgments are quick and automatic. Perrotin et al. (2008) further suggest that executive functioning is an important mediator of overall memory accuracy and thereby contributes to FOK validity in predicting recognition. Findings of a correlational study by Perrotin et al. (2008) relate that episodic FOKs may depend on executive-memory interaction in that executive processes coordinate and monitor information accessed during memory search.

FOK magnitude has been reported to increase with the degree of overlearning (Nelson, Leonesio, Shimamura, Landwehr, & Narens, 1982; Carroll, Nelson, & Kirwan, 1997). Thus, this study used differential repetition, in which some word pairs are repeated more often than others during encoding, to better contrast successful and unsuccessful FOKs. Overlearning, influenced by differential repetition, generates more information in memory about the word pairs that are repeated, which results in better FOK resolution. Hence, this better resolution allows for the use of functional magnetic resonance imaging (fMRI) to isolate brain areas that are active during successful FOKs, and thus also allows for a better comparison between successful and unsuccessful FOKs. This better resolution occurs because of the increased quality and quantity of information available in memory for the repeated items as opposed to the non-repeated items. Such additional accessible information acts as a basis for discrimination between items that later are or are not recognized.

Neuroimaging Review

Event-related fMRI is often used in studies of episodic memory as it allows for comparisons between successful and unsuccessful retrieval trials (Maril, Simons, Mitchell, Schwartz, & Schacter, 2003; Buckner et al., 1998). In general, event-related fMRI designs are ideal for studies involving signal changes associated with one or more kinds of behavioral trials, or events that comprise the trials, with respect to an intertrial interval (ITI) and to each other. For every trial type, trials consist of either an experimentally controlled or a participant-mediated event (D'Esposito, Zarahn, & Aguirre, 1999). This methodology has helped in the discovery of those brain regions active during episodic recognition and during retrieval of sensory details from prior presented information (Wheeler, Petersen, & Buckner, 2000).

Several event-related fMRI studies report activation of the prefrontal cortex (PFC) during FOK judgment. The PFC has generally been associated with memory monitoring, and some studies have even found a role for the PFC in the generation of accurate FOK judgments (Perrotin et al., 2008). According to Widner, Otani, and Winkelman (2005), patients with PFC deficits display less accurate FOK judgments, which is consistent with this finding. Schnyer et al. (2004) found that the right medial PFC may be important in producing accurate FOKs when they studied PFC impaired patients. Studies of frontal lobe lesion patients provide additional support in that these patients show impaired episodic FOK accuracy (Perrotin et al., 2008). Evidence from studies by Maril et al. (2003) and Jing, Niki, Xiaoping, and Yue-jia (2004) involving newly learned word pairs provide support that FOK judgments are associated with the left PFC. One study demonstrated that activity in the left dorsolateral PFC (DPFC), left anterior PFC (APFC), bilateral inferior PFC, and medial PFC increased with higher FOK judgments (Kikyo, Ohki, & Miyashita, 2002). Accurate FOK judgments are also associated with a frontal-temporal brain network in which the ventral medial PFC (VMPFC) plays a critical role in monitoring and evaluating during memory retrieval (Schnyer, Nicholls, & Verfaellie, 2005). This retrieval network purportedly includes the lateral temporal cortex and hippocampus (Schnyer et al., 2005).

In addition to investigating FOK judgments, fMRI has also been used to study R/K judgments. Greater activity is reported to occur during correct remember trials than in correct know trials in the left PFC, left lateral parietal, posterior cingulate, and medial temporal lobe (MTL) regions (Chua, Schacter, Rand-Giovannetti, & Sperling, 2006). Also, the right PFC and anterior cingulate are purportedly more active during correct know trials than in correct remember trials (Chua et al., 2006).

Overview of the Current Study

Although considerable progress has been made in FOK research, no event-related fMRI study has been conducted investigating episodic FOK judgments with a design that manipulates underlying memory strength using item repetition. Also, much of the neuroimaging literature focuses on brain activity related specifically to successful FOKs. The current study investigates the differences in activity between successful and unsuccessful FOK judgments to determine which regions are active in each case. Furthermore, this study explores the differences between high and low successful FOKs, between correctly recognized recollection and familiarity judgments, and between levels of repetition (one versus three).

The current study is an event-related fMRI study of episodic FOK judgments with a manipulation of repetitions: one versus three repetitions during encoding. Because a better memory trace is expected for repeated words than non-repeated words as a result of the overlearning design, it was hypothesized that the words that are repeated during encoding will have higher recall and recognition accuracy than those words presented only once. Additionally, it was expected that there would be a tighter relationship, or a higher correlation, between FOK and R/K judgments for those words repeated three times as compared to those presented only once due to the increased information in memory for repeated words. In other words, high FOKs are likely to coincide with remember judgments and low FOKs would likely coincide with know judgments more often for words with repeated exposures.

In terms of regions of activity, activity was expected in the DPFC, VMPFC, and the APFC in the FOK condition since these brain regions are important in memory and control processes. Furthermore, the replication of activation of the hippocampus and parahippocampus was hypothesized as these regions are involved in memory processes as well. Left PFC, left lateral parietal, posterior cingulate, and MTL regions were expected to be more active for correct recollection judgments, whereas the right PFC and anterior cingulate were expected to be more active for correct familiarity judgments.

Method

Participants

Nine younger adults (ages 18-26) from the Georgia Institute of Technology community participated in this study. Five of the participants provided behavioral data only and four provided fMRI data. Participants were native English speakers who met all necessary requirements according to the Functional Magnetic Resonance Imaging Health Screening Form (see Appendix A). Sessions were held 48 hours apart, so participants were required to commit to a second session before participating in the first. One credit per hour of participation, or three credits in total, was assigned on Experimetrix following the completion of the second session.

Design

Session One. Practice trials were conducted to verify the understanding of instructions and were based on a short study list of five unrelated noun word pairs that did not appear in the actual learning phase study list. The study list contained 108 unrelated noun word pairs, for example, KITE - SKILLET (see Appendix B). In order to introduce differential repetition into the design, a randomly selected half of the study list was presented only once, while the remaining word pairs were each presented three times. The word pairs of this study list were presented in a random order.

Session Two: During Scanning. While in the scanner, there were three experimental conditions: "Recall", "Read and Say," and "FOK." "Recall" and "Read and Say" phases were counterbalanced across runs and participants. An "FOK" phase concluded each run.

The "Recall" phase consisted of 12 trials in which cues were presented from CUE-TARGET pairs. Cues were randomly selected from the initial study list of word pairs. The "Recall" condition serves as a baseline to isolate FOK judgment processes from memory retrieval processes that contribute to the activity present during FOK judgments. This condition is important since one contrast of interest is that of "Recall" with "FOK" to determine whether or not FOK judgment processes involve mechanisms separate from those governed by cued recall retrieval search and evaluation. Participant target responses were recorded.

There were eight "Read and Say" trials in which a single word was presented to be read aloud. The "Read and Say" word list was comprised of nouns not included in the word pair study list (see Appendix C). The "Read and Say" condition serves as a baseline to isolate FOK judgment processes from language comprehension and production processes that contribute to the activity present during FOK judgments. Contrasting "Read and Say" and "FOK" conditions allows for the isolation of these FOK judgment processes during fMRI data analysis. Thus, both the “Recall” and “Read and Say” data serve as baselines for when we parse out the FOK signals later.

In the 12 “FOK” trials, participants were required to read aloud the presented cue and make an FOK judgment for that cue. Participants made responses with their index and middle fingers of each hand using an inline four-button response box positioned comfortably across their lap with four FOK judgment options assigned to it: 0-20%, 21-50% (with a benchmark of about 40%), 51%-80% (with a benchmark of about 60%), and 81-100%. A low FOK judgment (e.g., 0-20%) signifies that the participant does not think he or she will recognize the correct word pair for the given word in a later recognition test and will most likely have to guess, whereas a high FOK judgment (e.g., 81-100%) means that the participants are extremely confident that they will recognize the correct word pair in a later recognition test.

All three phases also included null trials between each response screen. Null trials were necessary to distinguish between events due to the sluggishness of the hemodynamic response (D’Esposito et al, 1999). Each phase contained a combination of 2, 4, and 8 second nulls. As there were 32 nulls in total, they were randomly distributed so that half of the nulls were 2 seconds, a fourth of the nulls were 4 seconds, and a fourth of the nulls were 8 seconds. Thus, “Recall” and “FOK” phases included six 2 second nulls, three 4 second nulls, and three 8 second nulls, while the “Read and Say” phase included four 2 second nulls, two 4 second nulls, and two 8 second nulls.

Session Two: After Scanning. Following the fMRI scanning, participants completed a four alternative forced choice recognition task with remember/ know judgments. This task consisted of 108 questions, one for each word-pair studied during Session One. Each question was comprised of four word pair options, one of which was a correct word pair from the study list. The three incorrect word pair options were in the format of CUE – DISTRACTOR and the correct answer choice was in the format of CUE – TARGET. All four choices contained the same cue for each numbered test item. All distractors were target words from other word pairs of the study list. Correct answer choices were randomly but equally distributed across the four columns, and each distractor appeared once in each of the three columns that did not contain the distractor as a target. Distractors were also randomly distributed across the columns. To the right of the four possible answer choices in each numbered item were the options R, remember, and K, or know. The recognition test was not timed.

Procedure

Session One. In the proposed study, participants were scheduled for two sessions, 48 hours apart. Given the length of the study list and the repetition incorporated into the design, this delay was considered to be sufficient for the mean recall and recognition to be below ceiling. Additionally, this delay was most convenient for student participants' schedules. This first session of the experiment was conducted in the mock MR scanner at Georgia Tech with the use of an E-prime program run on a computer. The mock scanner recreates the physical enclosure, table, ambient sounds and head coil of the MRI scanner. First participants completed informed consent and demographic questionnaire forms. All instructions pertaining to both sessions were explained, followed by a set of practice trials. Finally, participants were presented with the word pair study list and required to try to remember as many of these word pairs as possible for the second session. The duration of each word pair presentation was four seconds. This learning phase concluded Session One. This first session lasted approximately one hour and occurred in the mock MR scanner at the Georgia Institute of Technology campus.

Session Two. Forty-eight hours later, scan participants arrived at the Emory University facility for the second session of the study. Behavioral pilot participants completed this portion of the experiment in the mock MR scanner at the Georgia Institute of Technology. Neuroimaging data was collected with the use of an MRI scanner. Participants lay on their backs in the scanner and stimuli were projected onto a screen through a mirror that was mounted on the head radio-frequency (RF) coil. Stimulus presentation was controlled with an E-prime program run on a Dell Inspiron 9300 personal computer. Vocal responses were recorded with a Sony digital voice recorder. A structural scan of approximately ten minutes in duration was collected at either the beginning or the end of the allotted hour for scanning.

During scanning, participants viewed nine runs of the three different phases: “Recall,” “Read and Say,” and “FOK.” Instruction screens for “Recall” and “Read and Say” blocks were viewed for 3.5 seconds each, and the “FOK” instruction screen was viewed for 7.5 seconds. All instruction screens were followed by a 0.5 second null display, which consisted of a single fixation cross. In the “Recall” phase, participants were allotted four seconds to either state aloud the matching target word or respond “no answer” if he or she was unable to make a guess. Participants were given two seconds to read the presented word aloud in the “Read and Say” phase. Finally, in the “FOK” phase, participants read the cue aloud and made their FOK judgments using the aforementioned rating scale within the allotted four seconds.

Following the hour in the scanner, participants completed a four alternative forced choice recognition test consisting of all the previously studied word pairs. In addition, participants chose one of two options for each word pair on the recognition test: “Remember” or “Know.” Participants selected “Remember” if the pair they chose was chosen because they had a specific memory related to the pair, and they selected “Know” if the pair they chose was chosen because it either seemed familiar or it was a guess. Participants were allotted up to 45 minutes to complete the recognition task (the task was essentially not timed), after which they were debriefed.

Behavioral data was analyzed using E-prime Data Aid, Microsoft Excel, and SPSS software. Neuroimaging data was reconstructed, processed, and analyzed using Statistical Parametric Mapping 5 (SPM5) software run through MATLAB. Following reconstruction, head-motion artifacts and differences in slice acquisition timing were corrected. Data were then smoothed with a Gaussian filter (FWHM = 6 mm) before analysis with a modified General Linear Model (Worsley and Friston, 1995). Contrast images were computed for each of the three phase conditions versus the fixation baseline conditions, as well as for successful versus unsuccessful FOKs, successful high versus successful low FOKs, one versus three repetitions, and correctly recognized recollection versus familiarity.

Results

Behavioral Data. For the behavioral analyses we combined the data from the five pilot and the four fMRI participants ($N = 9$). An alpha level of 0.05 was used for all statistical tests. As seen in Table 1, means of recall, FOK, recognition accuracy, and R/K for single presentations of items during encoding were greater than for items presented three times during encoding. A repeated measures analysis was conducted with repetitions as the within-subject variable. As there were only two levels of the within-subject variable, the sphericity assumption was met. The results indicate that there was a significant effect of repetition on mean recall ($F(1, 8) = 7.73$, $p = 0.02$, $d = 1.09$), mean FOK ($F(1, 8) = 31.09$, $p = 0.001$, $d = 1.25$), mean recognition accuracy ($F(1, 8) = 25.36$, $p = 0.001$, $d = 1.18$), and mean R/K ($F(1, 8) = 40.10$, $p < 0.001$, $d =$

1.69), with increased memory performance and higher FOK judgment ratings for items presented three times. The effect sizes of these results are large according to Cohen's (1988) standards.

Gamma correlations between FOK and recognition for all items and for unrecalled items only were both greater than chance as the 95% confidence interval did not include zero (see Table 2), which indicates that FOKs do predict later recognition performance even in the event of a failed recall attempt. Also above chance were the gamma correlations between FOK and R/K for all items, for unrecalled items only, and for unrecalled and correctly recognized items (see Table 2). These results demonstrate that items rated with high FOKs are more likely to be recollected than those items rated with low FOKs, which are more likely to be judged as familiar. The gamma correlation between recognition and R/K for unrecalled items only was greater than chance ($M = 0.80$, $SE = 0.08$), which indicates that participants give higher recollection ratings for correct responses than incorrect responses. Additionally, the gamma correlations between FOK and recognition, between FOK and R/K, and between recognition and R/K were computed for one versus three word pair repetitions (see Table 3).

A repeated measures analysis was conducted with repetitions as the within-subject variable. There was no statistically significant effect of repetition on any of the computed gamma correlations, most likely due to an issue of statistical power. Hence, there was no effect of repetition on the gamma of FOK with recognition for all items ($F(1, 8) = 0.91$, $p = 0.37$, $d = 0.42$) or unrecalled items only ($F(1, 8) = 0.54$, $p = 0.48$, $d = 0.32$), nor on the gamma of FOK with R/K for all items ($F < 1$, $d = 0$), unrecalled items only ($F(1, 8) = 1.31$, $p = 0.29$, $d = 0.52$), or unrecalled and correctly recognized items ($F(1, 8) = 1.34$, $p = 0.28$, $d = 0.56$). There was also no effect of repetition on the gamma of recognition with R/K for unrecalled items only, $F < 1$, d

= 0.02. Therefore, although repetition significantly affects memory performance, memory monitoring accuracy was not reliably affected by repetition in this sample.

Neuroimaging Data. FOK accuracy is measured as a correlation of FOK prediction values with recognition outcome. Hence, successful or accurate FOKs are those in which either high FOKs predict correct recognition or low FOKs predict incorrect recognition. Therefore, unsuccessful or inaccurate FOKs are those in which a high or low FOK does not properly predict either correct or incorrect recognition of an item, respectively. FOK ratings of greater than 50% are considered high FOKs, while those of less than or equal to 50% are considered low FOKs.

Contrasts of interest included successful or accurate versus unsuccessful or inaccurate FOKs, accurate high versus accurate low FOKs, one versus three repetitions, and remember versus know judgments for correctly recognized word pairs. All of these contrasts were run for unrecalled items only. The significance level for all contrasts was set to $p < 0.001$ uncorrected. An accurate by inaccurate FOK contrast yielded significant activation in the ventral lateral PFC (VLPFC) of one of four participants. The same participant also displayed significant activation in the APFC for an accurate high by accurate low FOK contrast. One out of the four participants displayed significant activity in the VMPFC for one versus three repetitions. Correctly recognized items judged as remembered yielded significant activity in the left DLPFC and APFC, the right VLPFC, and anterior cingulate, whereas correctly recognized items judged as familiar yielded significant activity in the right VMPFC.

Discussion

As expected, those words which were repeated during encoding resulted in higher recall and recognition accuracy than those words presented only once. Additionally, repetition had a significant effect on R/K and FOK judgments. Thus, the results support the hypothesis that repetition affects memory, possibly by allowing for the creation of a better memory trace for repeated items.

Repeated exposure was hypothesized to result in an increased probability for information about a target word being accessible when making an FOK or memory judgment. Thus, gamma correlations were expected to be higher for repeated words than for non-repeated words, most particularly for those of FOKs with R/K judgments. However, the results of the repeated measures analysis for all the gamma correlations were not statistically significant. Perhaps the lack of a statistically significant result is due to the small sample size or the nature of the gamma correlation. There are various arguments against using gamma correlations as they tend to be negatively impacted as a measure when there are extremes in the data. As some of the participants were close to ceiling on one or several of the measures, the lack of a statistically significant effect of repetition on FOK accuracy is inconclusive. However, this result also further highlights the differences between memory and metamemory. We cannot conclude that repetition is not a relevant cue for metacognitive monitoring, or for increasing FOK accuracy, from these results. However, a larger in-progress behavioral study in the Hertzog lab shows that repetition does affect FOKs in younger adults.

The data on the four persons with fMRI data provide interesting preliminary results that warrant further study. Activity was hypothesized to occur in several regions of the PFC and MTL for the various contrasts of interest. Accurate FOK conditions did result in significantly more activity in the VLPFC and APFC, which roughly coincides with the findings of PFC activity by Schnyer et al. (2005), although their findings related specifically to the VMPFC. When the statistical significance threshold was reduced to explore for potential results, a general trend of VLPFC, APFC, and anterior cingulate activity was evident in the accurate versus inaccurate FOK contrast. In the accurate high by accurate low FOK contrast, a general trend of PFC and MTL activity was apparent. These PFC regions included the dorsal PFC (DPFC) and APFC, while the MTL regions included the anterior and posterior cingulate.

Statistically significant results of brain activity for correctly recognized remembered items and for correctly recognized familiar items did not support the findings of Chua et al. (2006). Even when the threshold was reduced, correctly recognized remembered items displayed activity in the anterior and posterior cingulate, the right VLPFC, the left VMPFC, and the bilateral APFC and DLPFC. Meanwhile, the correctly recognized familiar items resulted in bilateral activity in the VMPFC, DLPFC, and APFC. With a reduced threshold, a general pattern of DPFC, APFC, VPFC, and anterior cingulate activity was evident in the one by three repetitions contrast.

In general, regions involved in memory and executive control processes were involved in FOK predictions and R/K judgments as was expected, but additional analyses would be beneficial in ascertaining involvement of regions of interest. Future analyses to be considered for the neuroimaging data include more detailed exploration of the PFC and MTL regions for FOK conditions as well as those brain regions that are a part of the retrieval network, such as the lateral temporal cortex.

This project will be continued in the summer in order to collect a complete set of young adult scan data ($N = 17$, $n = 12$ for scan participants). With additional scan data the contrast images can be normalized to the Montreal Neurological Institute (MNI) reference brain and additional analyses for both the behavioral and neuroimaging data can be conducted. Future studies may also investigate the effects of repetition on memory performance and FOK accuracy as a function of aging, with both older adult and younger adult samples.

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Table 1

Behavioral Means as a Function of Repetition

	Recall		FOK		Recognition Accuracy		R/K	
Repetition	M	SE	M	SE	M	SE	M	SE
One	0.03	0.01	2.17	0.16	0.55	0.06	0.28	0.07
Three	0.21	0.08	2.82	0.19	0.78	0.07	0.69	0.09

Table 2

Mean Gamma Correlations for FOKs with Recognition Accuracy and R/K Judgments

	Recognition		R/K	
	M	SE	M	SE
Gamma correlation (All words)				
FOK	0.35	0.11	0.59	0.07
Gamma correlation (Unrecalled words)				
FOK	0.23	0.10	0.43	0.11
Gamma correlation (Unrecalled and correctly recognized words)				
FOK			0.45	0.08

Table 3

Mean Gamma Correlations for FOKs and Recognition as a Factor of Repetition

	Recognition		R/K	
	One	Three	One	Three
	M (SE)	M (SE)	M (SE)	M (SE)
Gamma correlation (All words)				
FOK	0.11 (0.31)	0.32 (0.63)	0.51 (0.29)	0.51 (0.31)
Gamma correlation (Unrecalled words)				
FOK	0.46 (0.28)	0.20 (0.61)	0.46 (0.27)	0.25 (0.50)
Gamma correlation (Unrecalled and correctly recognized words)				
FOK			0.45 (0.38)	0.20 (0.50)
Gamma correlation (Unrecalled words)				
Recognition			0.65 (0.34)	0.64 (0.65)

Appendix A

Georgia Institute of Technology Biomedical Imaging Technology Center (BITC)
Functional Magnetic Resonance Imaging Health Screening Form

Name: ______________________________________
Cell phone number: ____________________________

Gender: _____________________________________
Age: _______________________________________
Date of birth: _________________________________
Height: ______________________________________
Weight: ______________________________________

Ethnicity:
[ ] Hispanic or Latino
[ ] Not Hispanic or Latino

Racial Category:
[ ] American Indian/Alaska Native
[ ] Black/African American
[ ] Native Hawaiian/Other Pacific Islander
[ ] Asian
[ ] Hispanic/Latino
[ ] White

Handedness
What hand do you normally use? (Put "+" in the column if you usually use that hand, "++" if you always use that hand, or one "+" in each column if you use both hands equally.)

Activity	Left	Right
Writing a message		
Drawing a picture		
Using a toothbrush		
Throwing a ball		
Using a pair of scissors		

Do you have any immediately family members who write with their left hand? ________

Language/Education
What was your first language? __________________________
Are you bilingual? [ ] Yes [ ] No
With what language(s)? _______________________________
Starting with elementary school, how many years of education have you had? _______

Eyesight:
Do you wear:
[ ] Glasses [ ] Bifocals [ ] Reading glasses [ ] Contacts [ ] None (normal vision)

Is the prescription for one of the eyes much stronger than the other? [ ] Yes [ ] No
Do you know what your prescription is? Left _________ Right __________

Do you have an astigmatism? [ ] Yes [ ] No
Are you color blind? [ ] Yes [ ] No

General Health:

How would you rate your general health? [ ] Poor [ ] Fair [ ] Good [ ] Excellent

Do you have or have you ever had any of the following medical problems?

[ ] No [ ] Yes Cataracts – if yes, have you had them removed? [ ] No [ ] Yes
were there any complications? ___________________

[ ] No [ ] Yes Glaucoma, macular degeneration

[ ] No [ ] Yes Respiratory problems

[ ] No [ ] Yes Heart disease – if yes, list any medications: __________________

[ ] No [ ] Yes High blood pressure – if yes, list any medications: _____________

[ ] No [ ] Yes Low blood pressure or anemia – if yes, list any meds: __________

[ ] No [ ] Yes Diabetes – if yes, list any medications: ______________________

[ ] No [ ] Yes Arthritis, or other problems with hands or back – if yes, list any medications: ______________________

[ ] No [ ] Yes Sickle cell anemia

[ ] No [ ] Yes Parkinson's/Alzheimer's

[ ] No [ ] Yes Seizure

[ ] No [ ] Yes Stroke

[ ] No [ ] Yes Lost consciousness for more than a few seconds

[ ] No [ ] Yes Brain damage

1. Do you have a cardiac pacemaker, hearing aid, or any other implant? (The high magnetic field interferes with the proper functioning of pacemakers. Metal implants may be bent, pulled out of place etc. Shrapnel, for instance from an old war wound, left lodged near vital organs may be pulled by the field.)

   [ ] No   [ ] Yes

2. Do you have any metal in your body? (This includes pins, screws, plates, or braces on your teeth.)

   [ ] No   [ ] Yes

3. Do you have any non-removable jewelry or body piercing? (Metal jewelry made out of materials such as surgical steel will tend to heat up and become uncomfortably warm. This is similar to what happens if you put a fork in a micro-wave oven.)

   [ ] No   [ ] Yes

4. Is there any possibility you could be pregnant?(While there are no known harmful side-effects of MRI, we would rather not take any chances. So we ask that if you might be pregnant you NOT take part in these studies.)

   [ ] No   [ ] Yes

5. Are you at all claustrophobic? (The MRI scanner is a very narrow enclosed space. It has been compared to a tanning bed or a torpedo tube. The coil (or helmet like device your head is placed in) is mere centimeters--possibly less--from the tip of your nose. Your head is placed in padding to help you hold it as absolutely still as possible. While you can get out of the magnet at any time during the experiment, if you are feeling seriously uncomfortable, you should be aware that it is an extremely confined space, and you will need to lie still for an hour or more.)

   [ ] No   [ ] Yes

6. Are you quite obese?(Because the space is so narrow, people who are extremely heavy or obese cannot participate.)

   [ ] No   [ ] Yes

7. Do you need glasses and can not wear contact lenses?(Most studies require you to respond to visual cues or instructions, so normal vision is usually required. In these studies, contact lens corrected vision is considered the same as normal vision.)

   [ ] No   [ ] Yes

8. Have you ever been seen by a:

   [ ] Neurologist   [ ] Psychiatrist   [ ] Psychologist (not a councilor)

9. What medications are you currently taking (pills/day, mg/pill)?

10. Do you ever take tranquilizers or sleeping pills?

    [ ] No   [ ] Yes

11. Have you ever taken medication for your nerves or other psychological medications?
[ ] No [ ] Yes

12. Do you use illegal drugs more than recreationally or occasionally?

[ ] No [ ] Yes

13. Are there any other physical or mental problems that you haven't mentioned so far?
[ ] No [ ] Yes

If yes, please describe:

14. How much do any of these issues/problems mentioned above interfere with your daily activities?

Appendix B

Recall Word Pair List

1 ACROBAT - MICROWAVE
2 ALARM - MITTEN
3 ALPHABET - SHADOW
4 ARMOR - SYRINGE
5 AUTHOR - CHERRY
6 BACKPACK - TORCH
7 BALLOON - NIGHTMARE
8 BASKET - GRAPH
9 BEETLE - COMEDIAN
10 BOULEVARD - OREGANO
11 BROTH - JUPITER
12 BUMPER - MIGRAINE
13 CABOOSE - MUSTARD
14 CACTUS - PARCEL
15 CARTOON - JELLO
16 CATCHER - WAREHOUSE
17 CHEEK - MAGICIAN
18 COLLAR - CAMPUS
19 CONE - TRIGGER
20 CONVENT - BOOTH
21 COOKBOOK - CURTAIN
22 COUGAR - RUST
23 CREEK - BRONZE
24 CRUST - DISC
25 DART - CEILING
26 DATE - PENGUIN
27 DIAPER - TROUT
28 DRAFT - CANVAS
29 FABRIC - BISON
30 FEAST - HYGIENE
31 FLANNEL - GROVE
32 FLUTE - CRITIC
33 FOAM - PINT
34 FRACTURE - SHACK
35 GAUZE - BUDGET
36 GENE - THUMB
37 GLOBE - BARK
38 GROWTH - DIVER
39 HARLEY - DEVICE
40 HEEL - DUNE
41 HORIZON - POTTERY
42 HOUND - PILL
43 HYMN - BEARD
44 JAZZ - LEDGE
45 JEEP - PORTRAIT
46 JUNGLE - CRAMP
47 KITE - SKILLET
48 LATIN - KNUCKLE
49 LEVER - FREEWAY
50 LOAF - SUEDE
51 LUNCH - CREW
52 MAGNET - REEF
53 MECHANIC - SPLINTER
54 METER - COLT
55 MINERAL - WALKER
56 MODEL - BEAKER
57 MOSS - SCALP
58 MOWER - TREASURE
59 NAUSEA - BRAIN
60 PADDLE - SHERIFF
61 PATIO - BRUISE
62 PEBBLE - CHEER
63 PEDAL - SKATE
64 PRODUCER - CAPTIVE

Recall Word Pair List (continued)

65	PUPPY - SYMPHONY	87	TENNIS - SEATBELT
66	PUZZLE - PERCH	88	THESAURUS - DEODORANT
67	RADIO - CAKE	89	THIGH - WASHER
68	RANCH - BLOCKS	90	TISSUE - VISITOR
69	REINDEER - FOUNTAIN	91	TOBACCO - GLANDS
70	RICE - COLONEL	92	TORTOISE - LASH
71	ROAST - TOUCHDOWN	93	TRIAL - FROST
72	ROOSTER - HARBOR	94	TRICYCLE - FRIAR
73	SALARY - COMA	95	TUNA - LEAK
74	SANDPAPER - CORPSE	96	TUSK - BLAZE
75	SCALLOP - CREASE	97	UMBRELLA - CLAW
76	SCREW - WALLET	98	UNIFORM - ICEBERG
77	SCROLL - TYPIST	99	VANILLA - LIMOUSINE
78	SERMON - TOENAIL	100	VENOM - DRIVEWAY
79	SHRUB - CHLORINE	101	VETERAN - LUMP
80	SOCKET - FOLDER	102	VIKING - REFEREE
81	SQUASH - VIDEO	103	VINEGAR - MASCARA
82	STAPLE - EAGLE	104	VIRUS - MONARCH
83	STEAM - LILY	105	WAIST - CEMETERY
84	STRATEGY - PICKLE	106	WARDROBE - CLOVE
85	TANGERINE - RIBS	107	WICK - CHAPTER
86	TELESCOPE - SWAMP	108	ZIPPER - MOSQUITO

Appendix C

Read and Say Word List

1	ADDICT	37	LOLLIPOP
2	ALUMINUM	38	MARGARINE
3	ANKLE	39	MATTRESS
4	ATOM	40	MERIT
5	BASEMENT	41	MISSILE
6	BLINDS	42	MOTEL
7	BRIDE	43	MUSHROOM
8	BRIDGE	44	NEWTON
9	BUMPS	45	OATH
10	BUTTON	46	PEER
11	CARESS	47	PEPSI
12	CHAMPION	48	PINE
13	CHILD	49	POPCORN
14	CHURCH	50	POSTAGE
15	COMB	51	PROPERTY
16	COUPLE	52	PUBLIC
17	CUSTOMER	53	PUCK
18	DANCER	54	QUILT
19	DRYER	55	RAYS
20	ELECTRON	56	RHYME
21	EXECUTIVE	57	ROBBER
22	GALAXY	58	ROOT
23	GRANITE	59	SEAM
24	HANDCUFFS	60	SPARROW
25	HAZE	61	STARS
26	HELPER	62	SWABS
27	HERB	63	TILE
28	HINDSIGHT	64	TRIBE
29	HYPER	65	TWISTER
30	JUNK	66	UPSTAIRS
31	LABEL	67	VALENTINE
32	LEGS	68	VODKA
33	LIMB	69	WAFFLES
34	LOBBY	70	WIMP
35	LOCATION	71	WORD
36	LODGE	72	ZUCCHINI