A Thesis

Entitled

The Effects of Depth of Processing and Handedness On Episodic Memory

By

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Submitted as partial fulfillment of the requirement for
the *Master of Arts in Psychology*

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An Abstract of

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A large body of neurological studies indicates that both hemispheres of the brain are active during different memory processes. Mixed-handers, who have very close interhemispheric interaction, have been demonstrated to have superior episodic recall compared to strong-handers, whose interhemispheric communication is not as closely integrated. Previous studies involving episodic memory and handedness have focused on intentional memory, where information is willfully encoded with the knowledge that it will be needed later. Interestingly, incidental memories, which form without conscious effort, have been found to be nearly as durable as intentional memories. This study attempted to extend previous findings indicating a mixed-handed advantage for intentional episodic memory to incidental episodic memory using a levels of processing (LOP) paradigm. Attention to incoming information at different LOP during encoding has been shown to greatly affect subsequent episodic memory performance. Deeply processed information, which has been subjected to many elaborative processes, generates more retrieval paths and is much more easily recalled than shallowly processed information, which receives little elaboration. 182 participants were induced to form episodic memories under several encoding conditions representing a continuum of LOP. Three conditions relied on incidental encoding while a fourth relied on intentional encoding. Episodic recall for word lists was tested. Results replicated earlier findings in demonstrating LOP effects as well as confirming predictions that mixed-handers superior interhemispheric interaction would lead to better performance compared to strong-handers. Handedness differences were found to extend to incidental memory, with mixed-handers engaged in deep processing yielding the best recall performance. Strong-handers were also found to make significantly more recall errors than mixed-handers, with error rate closely related to strength of handedness. The results indicate that handedness differences arise at retrieval, and suggest follow-up studies that could confirm this by stimulating hemispheric interaction via saccadic eye movements.

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Chapter One

Introduction

Sometimes it is impossible to remember something important no matter how hard we try, while irrelevant information can be quite easy to recall. Even more frustratingly, the amount of conscious effort we put into creating an important memory does not always guarantee that it will be retrieved when needed. A key to explaining why recall can be so inconsistent is by exploring how incoming information is elaborated upon and the physiological structure of memory itself.

Memory is a complex and diverse group of neurological functions that spans throughout the brain, from the limbic system to the cerebral cortex. To get a clearer picture of the specific physiological processes of memory, Cabeza and Nyberg (2000) conducted a review of 275 studies comparing brain activity during episodic encoding and retrieval. They concluded that encoding and retrieval of episodic memories relies on bilateral patterns of brain activity. Generally, brain activity during encoding is confined to the left hemisphere, while the right hemisphere is usually active during retrieval.

To further describe the how the hemispheres interact with regard to memory Tulving et al. (1994) conducted a review of PET imaging studies. From their findings they proposed a Hemispheric Encoding/Retrieval Asymmetry (HERA) model of verbal episodic memory. HERA suggests the left prefrontal cortex is responsible for encoding episodic memory, while the right hemisphere is involved in episodic retrieval. The interaction of both hemispheres is necessary for optimal memory performance. In support of this theory, Cronin-Golomb, Gabrieli, and Keane (1996) found that patients who had undergone callosal section, the surgical severing of the corpus callosum, exhibited very specific memory deficits. They had unimpaired implicit memories, which are accessed via cortical substructures, but impaired episodic memory, presumably arising from the disconnect between left hemisphere-based encoding and right hemisphere-based retrieval processing. Zaidel (1995) found that these "split-brain" patients are still quite capable of retaining new semantic memories but show a marked decrease in the ability to form new episodic memories, likely due the their markedly decreased interhemispheric communication. For instance, they would be quite capable of learning a new recipe, but would be unable to remember the act of cooking dinner. Habib, Nyberg, and Tulving (2003) found that many hemispheric asymmetries potentially exist that may contribute to the formation of episodic memory, and that any number of disruptions due to injury may lead to its impairment.

HERA predicts that two hemispheres that have the ability to work closely together will produce the best possible episodic recall. Several studies (Habib, 1991, Witelson & Goldsmith, 1991, Clarke & Zaidel, 1994) indicate that left-handedness and mixed-handedness is associated with larger corpus callosa. It is likely that these larger callosa are capable of supporting greater interhemispheric communication in mixed-handers. Mixed-handers, presumably due to higher levels of interhemispheric interaction, have better access to their right hemisphere processes, such as episodic memory retrieval, versus strong handers. Christman and Propper (2001) predicted that the greater degree of interhemispheric interaction in mixed-handers would facilitate episodic memory by enhancing interaction between left hemisphere based encoding and right hemisphere based retrieval processes. They measured handedness by means of the Edinburgh Handedness Inventory (Oldfield, 1971). Using a recall/recognition paradigm (Tulving, Schacter, & Stark, 1982) they found that episodic-explicit memory involves integration between the hemispheres, while implicit-semantic memory is unilateral. Increased activity in both frontal lobes during episodic encoding is generally associated with better episodic recall (Buckner, 2000).

Propper, Christman, and Phaneuf (2005) also used strength of handedness as an indicator for differences in interhemispheric communication. Mixed-handers were inferred to have increased interhemispheric interaction relative to strong right-handers. Mixed-handers were found to have superior recall of both lab-based and real-world episodic memories vs. strong-handers. Propper and Christman (2004) found that mixed-handers tended to base recognition memory on explicit “remembering”, while strong-handers tend to base it on implicit “knowing”. Christman, Propper, and Dion (2004) found that strong right-handedness was associated with higher rates of false memories than mixed-handers. Their results confirmed the association of mixed-handedness facilitating episodic recall. Using a bilateral saccadic eye movement paradigm, Christman, Propper, and Brown (2006) attempted to determine if a mixed-handed advantage for episodic memory was due to differences in encoding vs. retrieval. After their participants engaged in brief saccadic eye movements, which have been demonstrated to facilitate increased interhemispheric interaction, participants recalled their earliest childhood memory. Mixed-handers recalled significantly earlier childhood memories versus strong-handers, indicating that mixed-handedness offsets childhood amnesia. Since interhemispheric interaction was not stimulated at encoding, but rather at retrieval it was inferred that this is where handedness differences in memory arise.

It has been clearly demonstrated that hemispheric interaction influences memory performance. However, there are cognitive factors during encoding and retrieval that are also independently capable of affecting recall. Episodic memory, the memory for a specific experience, often forms incidentally, without the explicit knowledge it will be accessed in the future. Intuitively, the desire for later recall seems to be a key factor in the durability of memory. Intending to remember an event would seem to be a necessary step to forming an enduring episodic memory. To see if this was the case, Hyde and Jenkins (1973) presented participants with a list of words and asked various questions about them; one group was asked whether each word contained the letter “e” or the letter “g” (a shallow task), while a second group was asked to rate the pleasantness of each word (a deep task). Half of the participants in each group were informed beforehand that they would later be given a test of their recall, while the other half was not. Surprisingly, participants who were informed of the test did not perform significantly better than those who were given the test without warning. This indicates that learner intent, represented here by the participants’ desire to recall as many words as possible, had no appreciable effect on recall. Instead, the kinds of questions participants were asked determined their subsequent memory performance. Shallow questions about the word lists, such as letter frequency, yielded relatively poor recall, while deep questions, such as word meaning, yielded the best recall.

In a landmark study, Craik and Lockhart (1972) introduced a processing model of memory encoding which proposed that traces, the neurological components of memory, form as a result of routine perceptual analysis of stimuli. They believed that the strength, and ultimately the longevity of a memory trace, was directly proportional to the complexity of mental operations carried out on it during encoding. They further theorized that short and long term memory were virtually identical processes, with the only difference between them being the strength of their respective traces. Short-term memories are only briefly accessible because they are composed of weak traces, with few retrieval paths, and are quickly disrupted by natural biological processes in the brain. Long-term memories endue because they are composed of strong traces, with many retrieval paths, which are much more resistant to neurological change.

A key to understanding why some memory traces form more strongly than others is the effect of differences in processing during the encoding process. Incoming sensory information is capable of being attended to by many different levels of processing (LOP), which can greatly influence how it is perceived. Craik and Lockhart (1972) proposed the strength of a memory trace is a direct function of the depth of processing used in creating it. Depth of processing refers to the degree of associations made during information processing. They further explained that levels of processing fall on a continuum from ‘shallow’ to ‘deep’ as processing operations elaborate and grow increasingly more complex. Shallow processing is viewed as gross and superficial analysis of information, such as a stimulus’ most blatant characteristics. Deep processing requires subtle attention, and most importantly, the connection of new information and associations to preexisting knowledge.

In a series of experiments Craik and Tulving (1975) further explored LOP effects on episodic memory. Their participants were asked to make a series of judgments about lists of words and were then tested for recall. Questions about each word, in a yes/no answer format, were designed to elicit processing at various LOP. Structural questions (e.g. about the word's appearance or physical nature) were presumed to rely on shallow levels of processing, phonemic questions (e.g. about the word's rhyming structure) represented mid-level processing, and semantic tasks (e.g. about the word's meaning) represented a deep level of processing. After a series of trials participants were given an unexpected recall test. Results were consistent with LOP theory, with performance (hit rate) improving from less than 20% for words with structural questions to over 96% for words with semantic questions. Clearly, the LOP employed during encoding profoundly affects episodic recall.

Craik and Tulving (1975) also successfully replicated Hyde and Jenkins (1973) findings that learner intent had little effect on subsequent recall by not informing half of their participants that there would be a recall test at the conclusion of one experiment. They found that participants who intended to remember as much of the stimuli as possible versus those who did not had approximately the same recall performance. The only factor found to impact recall was the participants' level of processing.

It is worth mentioning that while LOP effects can be very robust they do have clear constraints. Challis, Velichovsky, and Craik (1996) found that LOP effects are limited to conditions with similar encoding and retrieval characteristics. For instance, deeply processed lexical information does not aid in the verbal recall of the same information. They allowed participants to carry out many successive shallow operations on a stimulus word, such as font and letter judgments. Participants who performed a great deal of shallow processing did not yield the same quality of recall as those who were asked to perform a single brief deep operation, such as a sentence completion task. Thus, it appears that LOP effects are not additive or strengthened by rehearsal effects.

Craik and Tulving (1975) found reaction time to be associated with depth of processing. As LOP deepen reaction time generally increases. This indicates that greater elaboration requires more processing resources, and thus more processing time. However, this is not always the case, as Craik (2002) also notes that increased processing time at shallow levels cannot yield improved performance when compared to deep processing. Every study examining LOP should measure reaction time and be careful not to infer depth of elaboration based solely on reaction time performance. Difficult, shallow tasks, which produce long reaction times generally do not yield recall performance greater than simple, shallow tasks, which produce shorter reaction times. The structure of questions used to elicit various LOP must be carefully chosen to be truly represent vie of the continuum of processing.

In order to study incidental encoding many LOP studies do not inform participants that they will be actively forming new memories. In contrast, all of the studies finding mixed-handed advantages in episodic memory by Christman and colleagues employed effortful, intentional encoding. While intentional encoding is key to learning, most important memories in life are incidental. Accordingly, the purpose of the current study is to examine the nature of handedness differences in episodic memory under conditions of incidental encoding. The LOP paradigm provides a robust framework for studying incidental learning. To the extent that the previously observed handedness differences arose at the retrieval stage, as suggested by Christman, Propper, and Dion (2004) and by Christman, Propper, and Brown (2006), then it is hypothesized that a mixed-handed advantage will be larger for deeper, relative to shallow, levels of processing, as deeper levels lead to an increase in available retrieval paths. In contrast, to the extent that the superior episodic retrieval found for mixed-handers reflected deeper levels of encoding, then it is hypothesized that the mixed-handed advantage should remain constant across all encoding conditions.

Chapter Two

Method

Participants

Participants consisted of 182 undergraduate students from the University of Toledo. They were taken from a subject pool and received credit in a psychology course for their participation. As strong left-handers make up only a small proportion of the population, and any analysis with such small N is difficult, three strong left-handed participants' data were discarded from analysis. In terms of sex, the sample included 115 females and 64 males.

Handedness was assessed by use of the Edinburgh Handedness Inventory (EHI) (Oldfield, 1971), which asks about hand preference for ten common activities such as throwing, writing, or striking a match (see Appendix B for a copy). Responses are given on a five-point scale ranging from "always left" to "no preference" to "always right". Scores can range from -100 to 100 but absolute values are used to focus on the distinction between mixed and strong-handers. In order create two handedness groups, one representing participants who largely relied on a single hand for most EHI task vs. those who had less of a strong hand preference, a median split was performed. As a result, absolute value scores on the EHI ranging from 80 to 100 were considered strong-handers and absolute value scores ranging from 75 to 0 were considered mixed-handers. The median split produced 104 strong-handed and 75 mixed-handed participants.

Materials

The stimulus materials were presented on a Power Macintosh computer with a 17” CRT monitor. Stimuli were presented under the control of the Reaction Time module of the MacLaboratory program v.3.0.2. Stimulus materials (See Appendix A) were adapted from Craik and Tulving (1975).

Design

Handedness was measured using the EHI. Since the experiment focused on comparing mixed and strong right-handers only, there are two levels of the independent variable handedness – ‘mixed-handers’ and ‘strong-handers’.

Prior research indicated a potential interaction between handedness, sex, and memory performance. Participants’ sex was assessed by self-report, and sex was also included as an independent variable in analyses.

The third independent variable in the current study was encoding condition (EC): the level of processing elicited by a participants' set of questions. There were four conditions: structural, phonemic, semantic, and intentional encoding conditions. Thus, each of the dependent variables was analyzed using a 2 (Handedness: mixed vs. strong) X 2 Sex (female vs. male) X 4 (Encoding Condition: structural, phonemic, semantic, intentional) design, with all variables being between-subjects.

Three dependent variables were analyzed:

1. Words Correctly Recalled: The total number of words correctly recalled by participants at the conclusion of the experiment.
2. False Alarms: The number of words incorrectly recalled by participants.
3. Reaction Time: The time in milliseconds participants took to answer yes/no

questions about each word they viewed.

Participants were randomly assigned to one of the four encoding conditions by the computer. Of 182 total participants 41 were assigned to the structural encoding condition, 48 to the phonemic encoding condition, 48 to the semantic encoding condition, and 45 to the intentional encoding condition. To control for recency effects, all participants took a mandatory five-minute break between making word judgments and writing out the words they recalled.

Procedure

The procedure followed was consistent with Craik and Tulving (1975). Participants were tested individually and informed they would be taking part in a study of word perception. After an informed consent sheet was signed, handedness was assessed using the EHI. Participants were then seated at the computer, which displayed instructions for completing the word trials. Encoding in the structural, phonemic, and semantic conditions involves incidental learning, so participants were not informed their recall of the words would be tested later. Participants in the intentional condition were informed that they would be later tested for their memory for words presented. The computer displayed a series of 24 words in random order and asked participants to make judgments after each was presented. Participants in the structural condition were asked whether each word was printed in uppercase letters. Participants in the phonemic condition were asked whether each word rhymes with some other target word. Participants in the semantic condition were asked whether or each word fit a particular sentence frame. Finally, participants in the intentional condition were asked to study each word and attempt to remember it using any strategy they preferred and were reminded they would be tested on their recall later. Each question was in 'yes' and ‘no' answer format, with the correct answer to half of the questions being 'yes' and the other half 'no'. In the incidental encoding conditions, the computer displayed the question for two seconds, then the target word for five seconds, and the subject then answered by pressing the appropriate key. The computer recorded the accuracy of response for each question, as well as the reaction time. Answer keys were counterbalanced so that half of participants’ response keys were alternate sides of the keyboard. In the intentional encoding condition, words were simply displayed on the computer screen for five seconds each while the participant studied them.

Participants were given a mandatory five-minute break following the word judgments where they were asked to sit quietly and relax. The experimenter then informed the participants in the incidental learning conditions that they were to take a surprise recall test that required writing down as many words presented by the computer as they could remember within 15 minutes. The intentional encoding condition shared an identical method except participants were already aware of the final memory test.

Chapter Three

Results

A 2 x 2 x 4 ANOVA was conducted to evaluate the effects of sex, handedness group, and four encoding conditions on the number of words correctly recalled. The results for the ANOVA indicated a significant main effect for encoding condition $F(3, 163) = 76.97$, $p<.01$, Cohen's d = .39, a significant main effect for handedness $F(1, 163) = 9.60$, $p = .002$, Cohen's d = .27, and a significant interaction between encoding condition and handedness, $F(3, 163) = 3.07$, $p = .029$, Cohen's d = .18. Mixed-handers tended to have higher correct recall scores across LOP than strong-handers. No significant main effect or interactions were found for sex. Mean correct recall performance for each encoding condition is presented in Figure 1.

Independent samples t-tests were used to further analyze the significant main effect of encoding condition on words correctly recalled. The comparison of structural and phonemic conditions found no significant difference, $t(88) = .178$, $p = .859$. The comparison of structural and semantic conditions yielded significant results, $t(88) = -8.285$, $p = .001$, as did the comparison of phonemic and semantic conditions $t(94) = -8.29$, $p = .001$, and the comparison of semantic and intentional conditions $t(92) = -4.65$, $p = .001$.

Independent samples t-tests were also used to further analyze the significant interaction between encoding condition and handedness on words correctly recalled. The comparison of handedness groups for the structural encoding condition did not yield a significant effect, $t(35) = -0.39$, $p = .698$, nor did the comparison of handedness groups for the phonemic encoding condition, $t(46) = 0.37$, $p = .713$. The comparison of handedness groups for the semantic encoding condition yielded significant results, $t(46) = 3.24$, $p = .002$, as did the comparison of handedness groups for the intentional encoding condition, $t(44) = 2.22$, $p = .031$, with mixed-handers exhibiting higher levels of correct recall in both conditions.

A 2 x 2 x 4 ANOVA was conducted to evaluate the effects of sex, handedness group, and four encoding conditions on the number of words incorrectly recalled (i.e. false alarms). The results for the ANOVA indicated a significant main effect for handedness $F(1, 163) = 5.03$, $p = .026$, Cohen's d = .29 , with mixed-handers exhibiting fewer false alarms, a significant main effect for encoding condition $F(3, 163) = 8.78$, $p<.01$, Cohen's d = .36, with the shallow levels of processing conditions exhibiting greater false alarm rates, and no significant interactions. No significant main effect or interactions was observed for sex. Mean false alarm rates are presented in Figure 2.

A 2 x 2 x 4 ANOVA was conducted to evaluate the effects of sex, handedness group, and the three incidental encoding conditions on mean reaction time. The results for the ANOVA indicated a significant main effect of encoding condition $F(2, 121) = 68.17$, $p<.01$, Cohen's d = .52, and no interactions. As LOP deepen reaction time significantly increases for each handedness group. No significant main effect or interactions was observed for sex. For mean reaction times by encoding condition, see Figure 3.

Annett's (2002) genetic model of handedness posits that a continuum of handedness from strong left to strong right exists in the population. Strength of handedness for our participants then falls across this continuum of possible EHI scores. A correlational analysis was used to determine the effects of degree of handedness as a continuous variable. The absolute value of EHI scores was used to represent strength of handedness. Surprisingly, there was no significant relationship between the number of words correctly recalled and strength of handedness, $r = -0.11$, $p = .135$. However, the relationship between words incorrectly recalled (i.e. false alarms) and strength of handedness was significant, $r = 0.16$, $p = .026$, with stronger degrees of handedness being associated with higher false alarm rates. Correlational analyses were also conducted on (i) the data for the two shallow encoding conditions combined (structural and phonemic), which did not yield handedness differences, and (ii) the data for the two deep encoding conditions combined (semantic and intentional), which did yield handedness differences. For the shallow encoding conditions, there were no significant correlations between strength of handedness and either correct recall or false alarms. In contrast, the correlations between strength of handedness and both correct recall, $r = -0.30$, $p = .004$, and false alarms, $r = 0.339$, $p = .001$, were significant for the combined deeper processing conditions. Figures 4 through 7 present scatterplots of deep versus shallow encoding conditions crossed with hits and false alarms.

Chapter Four

Discussion

The goal of this experiment was to extend previous research indicating a mixed-handed advantage for intentionally encoded episodic memory to conditions of incidental encoding employing Craik and Tulving's (1975) levels of processing paradigm. It was hypothesized that there would be a mixed-handed advantage for deep relative to shallow processing which would remain constant across all LOP.

We successfully replicated Craik and Tulving's (1975) findings of the levels of processing effect in the evaluation of the hypothesis. Although the shallow processing conditions of structural and phonemic processing did not differ significantly from one another as initially hypothesized, collapsing them together to represent shallow processing indicated LOP differences. The shallower LOP of the structural and phonemic conditions produced poor recall performance when compared to the collapsed deeper LOP of the semantic and intentional conditions. Analyzing these results by handedness, strong-handers and mixed handers showed differences in recall performance depending on encoding condition. As hypothesized, mixed-handers showed superior memory performance relative to strong handers for the intentional encoding condition and the deepest incidental level of processing condition (i.e. semantic). An analysis of false alarms indicated that strong-handers made significantly more errors in recall than mixed-handers. The correlational data indicates that while handedness yields no effects during shallow processing, strong-handers engaging in deeper processing are likely to retrieve less correct and more incorrect information than mixed-handers. These findings are consistent with the hypothesis that the episodic memory advantage observed in mixed-handers arises at the retrieval stage, and not encoding. The advantage for deeper, relative to shallower, levels of processing reflects the presence of a greater number of associations made during deep processing, with these associations providing multiple retrieval paths. Mixed-handedness appears to be associated with increased access to such retrieval paths during recall, consistent with past studies that have suggested that handedness differences in memory arise at the retrieval, not encoding, stage (Christman, Propper, & Brown, 2006, Christman, Propper, & Dion, 2004). Also consistent with Craik and Tulving (1975), we found mean reaction times for each incidental encoding condition to significantly increase as LOP progressively deepen, with no handedness differences in reaction time performance.

The current results demonstrate that previous reports of handedness differences under conditions of intentional learning extend to conditions of incidental learning which involve deeper levels of processing. Shallow LOP did not show handedness differences in recall performance. However, since the comparison of collapsed shallow and deep incidental encoding conditions did show significant performance differences, the intent to learn does not seem to be a factor in the observed handedness differences. Rather, the observed advantages in episodic memory reported for mixed-handed subjects appears to reflect their greater ability to access at retrieval the context and associations present during encoding. For example, while there are no handedness differences in episodic recognition memory, mixed-handers are more likely to base recognition on explicit recollection of the original episode, in contrast to strong-handers who are more likely to base recognition on simple familiarity cues (Propper & Christman, 2004).

The intentional encoding condition produced the best recall scores and demonstrated a nominal performance gain over the other incidental encoding conditions. While prior research has shown learner intent not to greatly impact recall it is still an important factor in explaining memory performance. Intentional recall was considered the deepest LOP in this experiment, and consistent with theory the deepest LOP will generally be the best recalled. However, this study did not address other factors that have been shown to influence memory. For instance, metamemory strategies during encoding have been demonstrated to have an important impact on subsequent memory performance (Craik, 2002). Participants in the intentional encoding condition could have used any number of strategies for remembering their list of words, from rote repetition to semantic grouping, each of which has their own effects on memory performance. Indeed, there is evidence for handedness differences in the use of semantic grouping in retrieval from semantic memory (Sontam & Christman, 2006). The kind of information participants are asked to process may also lead to biased recall. Rogers, Kuiper, and Kirker (1977) also demonstrated that self-referential information is encoded above other types of information. In an LOP paradigm their participants were more than twice as likely to recall words they believed were related to their self concept than words that were simply semantically encoded.

An alternative explanation for this experiment’s findings is that handedness differences arise during the elaborative process at encoding. One possible hypothesis is that mixed-handers may simply engage in more substantive encoding relative to strong-handers, and consistent with LOP theory will have optimal recall. Another hypothesis could be that strong-handers are relatively poor elaborators relative to mixed-handers, and thus suffer poorer recall. It is beyond the scope of this study to address the question of whether strength of handedness could contribute to elaboration differences for mixed and strong-handers, respectively. As an important follow-up, a study utilizing an eye movement paradigm (Christman et al, 2003) to stimulate interhemispheric interaction in both mixed and strong-handers could be conducted to make this determination. This study’s successful extension handedness differences to a levels of processing paradigm indicates elaborative processing likely varies as a function of handedness.

Chapter Five

References

Annett, M. (2002). *Handedness and Brain Asymmetry: The Right Shift Theory.* Hove, UK: Psychology Press.

Buckner, R. L., Jogan, J., Donaldson, D. L., & Wheeler, M. E. (2000). Cognitive neuroscience of episodic memory encoding. *Acta Psychologica*, 105, 127-139.

Cabeza, R. & Nyberg, L. (2000). Imaging cognition II: an empirical review of 275 PET and fMRI studies. *Journal of Cognitive Neuroscience*, 22, 266-272.

Challis, B. H., Velichovsky, B. M., & Craik, F. I. M. (1996). Levels-of-processing effects on a variety of memory tasks: New findings and implications. *Consciousness and Cognition*, 5. 142-164.

Christman, S.D., Garvey K. J., Propper, R. E., & Phaneuf, K. A. (2003). Bilateral eye movements enhance the retrieval of episodic memories. *Neuropsychology*, 17, 221-229.

Christman, S. D., & Propper, R. E. (2001). Superior episodic memory is associated with interhemispheric processing. *Neuropsychology*, 15, 607-616.

Christman, S. D., Propper. R. E., & Brown, T. J. (2006). Increased interhemispheric interaction is associated with earlier offset of childhood amnesia. *Neuropsychology*, 20, 336-345.

Christman, S. D., Propper, R. E., Dion, A. (2004). Increased interhemispheric interaction is associated with decreased false memories in a verbal converging semantic associates paradigm. *Brain & Cognition*, 56, 313-319.

Clarke, J. M., & Zaidel, E. (1994). Anatomical-behavioral relationships: Corpus callosum morphometry and hemispheric specialization. *Behavioral Brain Research*, 64, 185-202.

Craik, F. I. M. (2002). Levels of processing: Past, present, …and future?. *Memory*, 10, 305-318.

Craik, F. I. M., Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior*, 11, 671-684.

Craik, F. I. M., & Tulving, E. (1975). Depth of Processing and the retention of words in episodic memory. *Journal of Experimental Psychology*, 104, 268-294.

Cronin-Golomb, A., Gabrieli, J. D. E., & Keane, M. M. (1996). Implicit and explicit memory retrieval within and across the disconnected cerebral hemispheres. *Neuropsychology*, 10, 254-262.

Habib, M. . Gayraud, D., Olivia, A., Regis, J., Salamon, G., & Khalil, R. (1991). Effects of handedness and sex on the morphology of the corpus callosum: A study with brain magnetic resonance imaging. *Brain & Cognition*, 16, 41-61.

Habib, R., Nyberg, L., & Tulving, E. (2003). Hemispheric asymmetries of memory: the HERA model revisited. *TRENDS in Cognitive Sciences*, 7, 241-245.

Hyde, T. S., & Jenkins, J.J (1973). Recall for words as a function of semantic, graphic, and syntactic orienting tasks. *Journal of Verbal Learning and Verbal Behavior*, 1973, 12, 471-480.

Oldfield, R. (1971). The assessment and analysis of handedness. The Edinburgh

Inventory. *Neuropsychologica*, 9, 97-113.

Propper, R. E., & Christman, S. D. (2004). Mixed-versus strong-handedness is associated with biases toward 'Remember' versus "know' judgments in recognition memory: Role of interhemispheric interaction. *Memory*, 12, 707-714.

Propper, R. E., Christman, S.D., & Phaneuf, K.A. (2005). A mixed-handed advantage in episodic memory: A possible role of interhemispheric interaction. *Memory & Cognition*, 33, 751-757.

Rogers T. B., Kuiper N. A., Kirker W.S. (1977). Self-reference and the encoding of personal information. *Journal of Personality and Social Psychology* 35, 677-88.

Sontam, V., Christman, S.D., & Jasper, J.D. (2006). *Semantic flexibility*. Presented at the 47th Annual Meeting of the Psychonomic Society, Houston.

Tulving, E., Kapur, S., Craik, F. I. M., Moscovitch, M., & Houle, S. (1994). Hemispheric encoding/retrieval asymmetry in episodic memory: Positron emission tomography findings. *Proceedings of the National Academy of Science,* USA, 91, 2016-2020.

Tulving, E., Schacter, D. L., & Stark, H. A. (1982). Priming effects in word-fragment completion are independent of recognition memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 8, 336-342.

Witelson, S. F., & Goldsmith, C. H., (1991). The relationship of hand preference to anatomy of the corpus callosum in men. *Brain Research*, 545, 175-182.

Zaidel, D. (1995). Separated hemispheres, separated memories: Lessons on long term memory from split-brain patients. In R. Campbell & M. A. Conway (Eds.), *Broken memories: Case studies in memory impairment.* Oxford: Blackwell.

Figure 1. Correct recall as a function of encoding condition and strength of handedness. Error bars represent 95% confidence intervals.

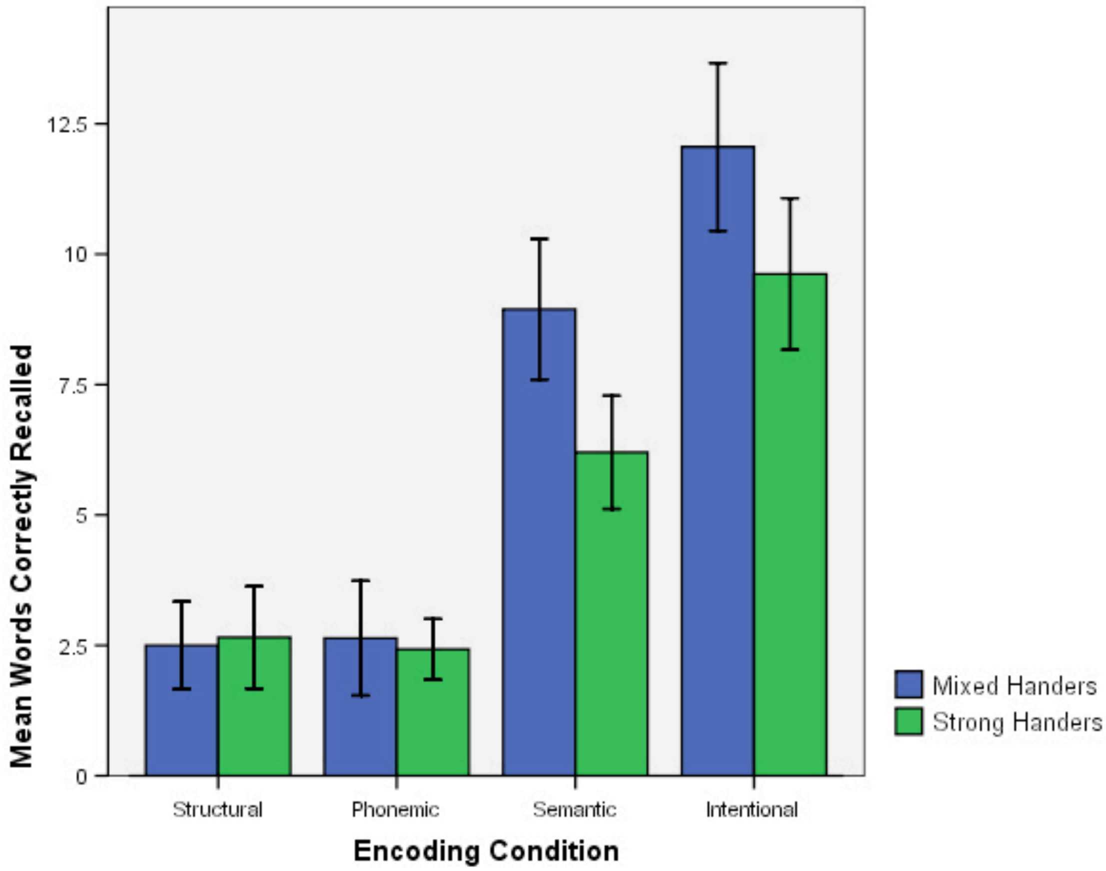


Figure 2. Incorrect recall (i.e. false alarms) as a function of encoding condition and strength of handedness. Error bars represent 95% confidence intervals.

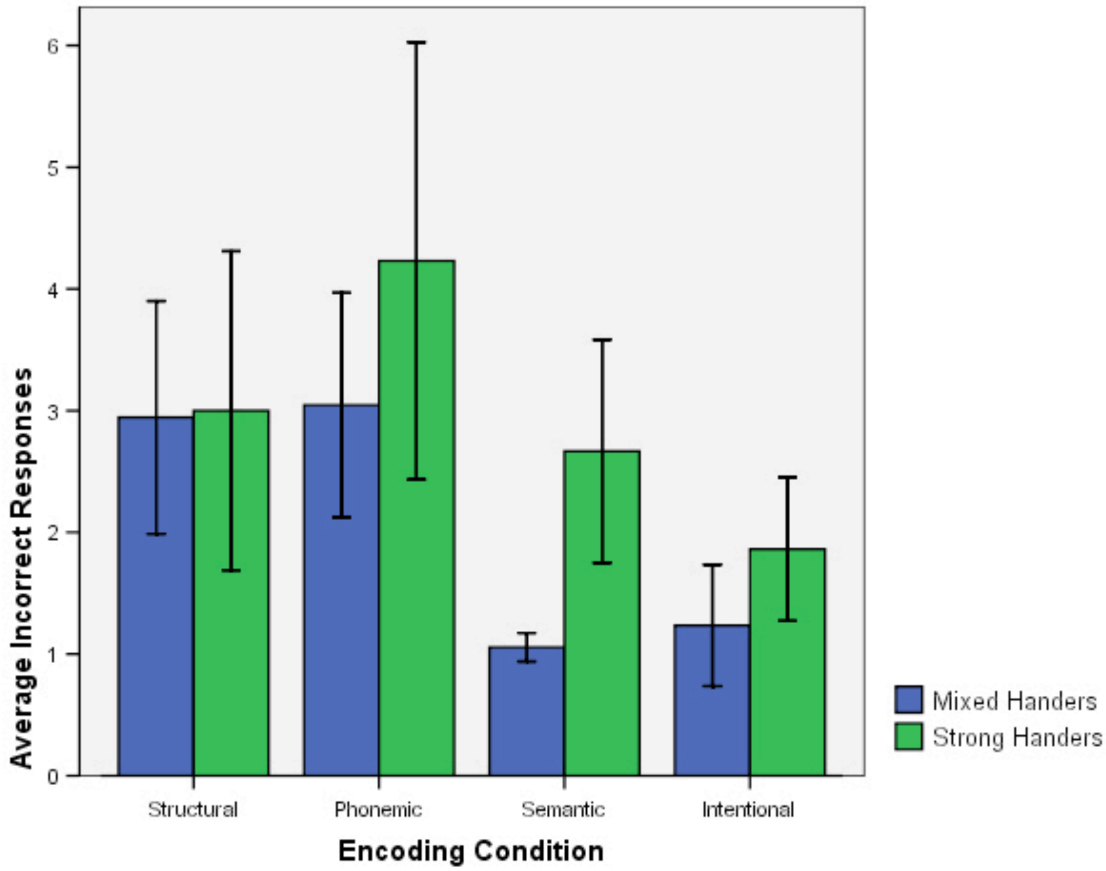


Figure 3. Reaction time (msec) as a function of encoding condition and strength of handedness. Error bars represent 95% confidence intervals.

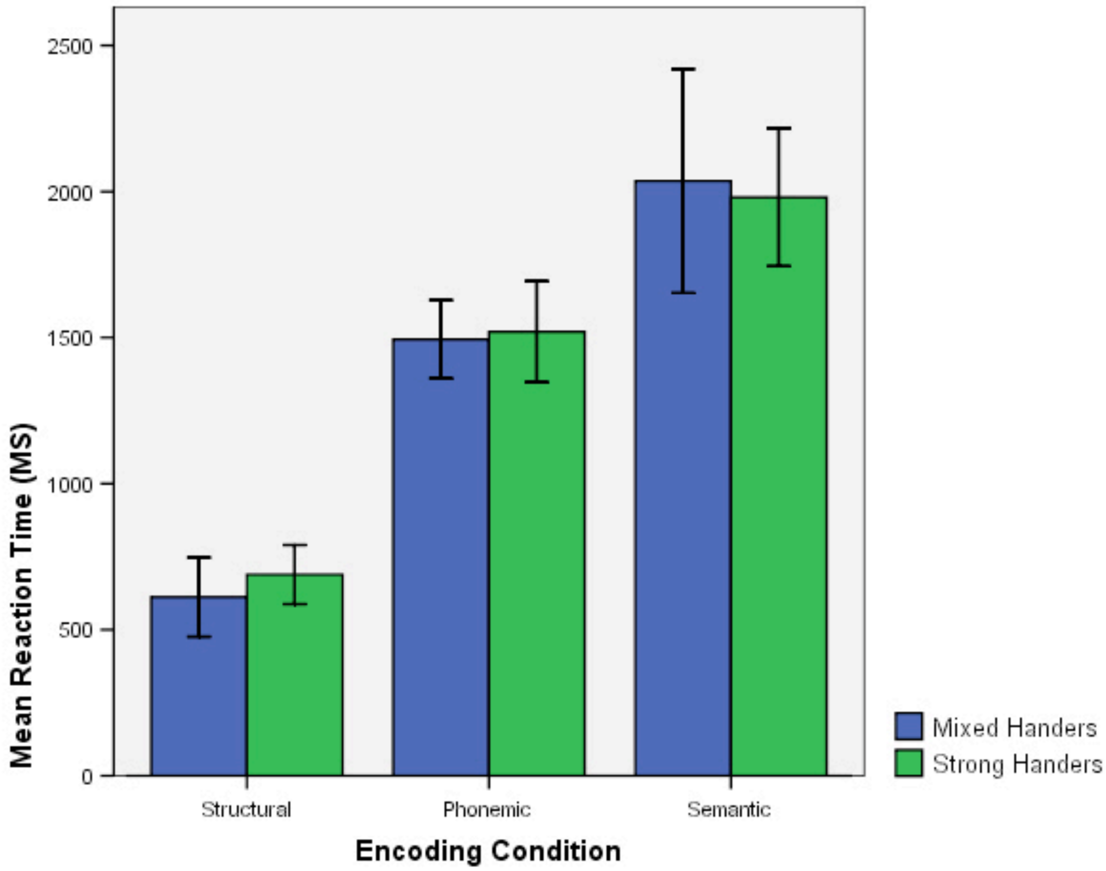


Figure 4. Scatterplot showing the relationship between number of words correctly recalled (i.e. hits) and strength of handedness in collapsed shallow processing conditions.

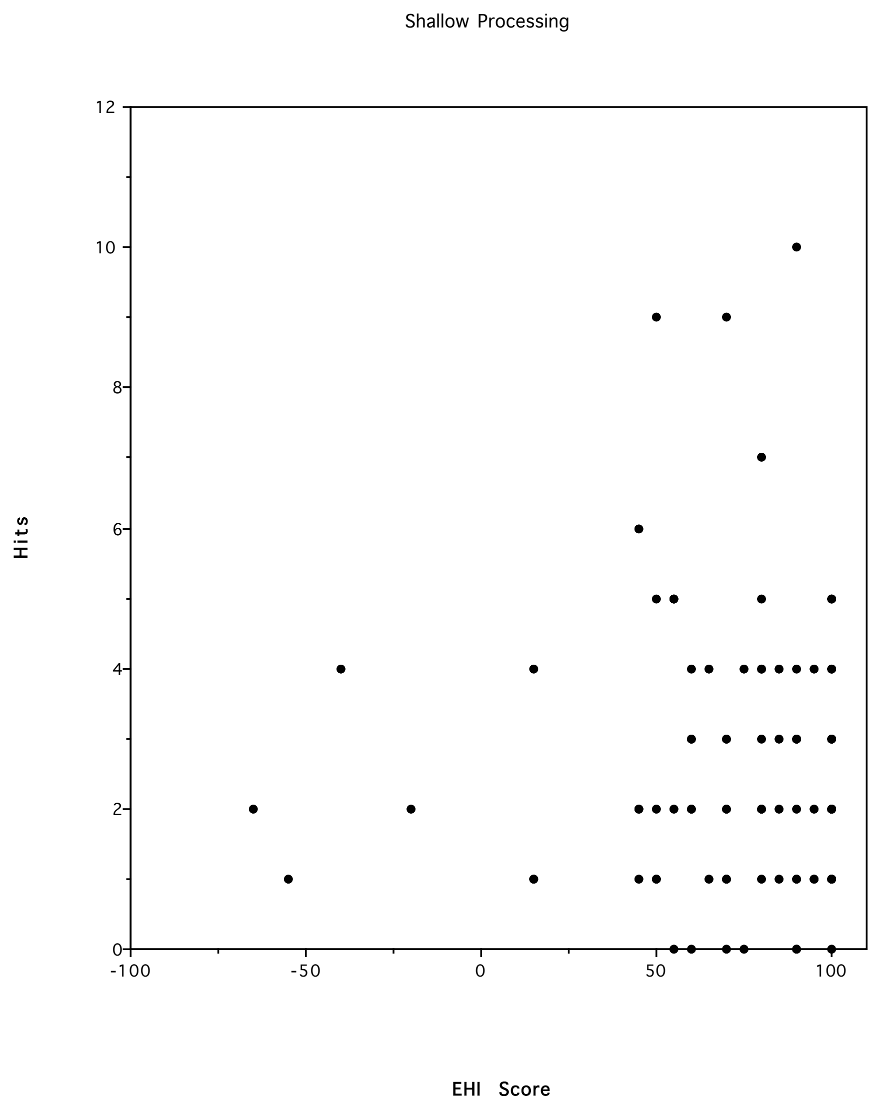


Figure 5. Scatterplot showing the relationship between number of words incorrectly recalled (i.e. false alarms) and strength of handedness in collapsed shallow processing conditions.

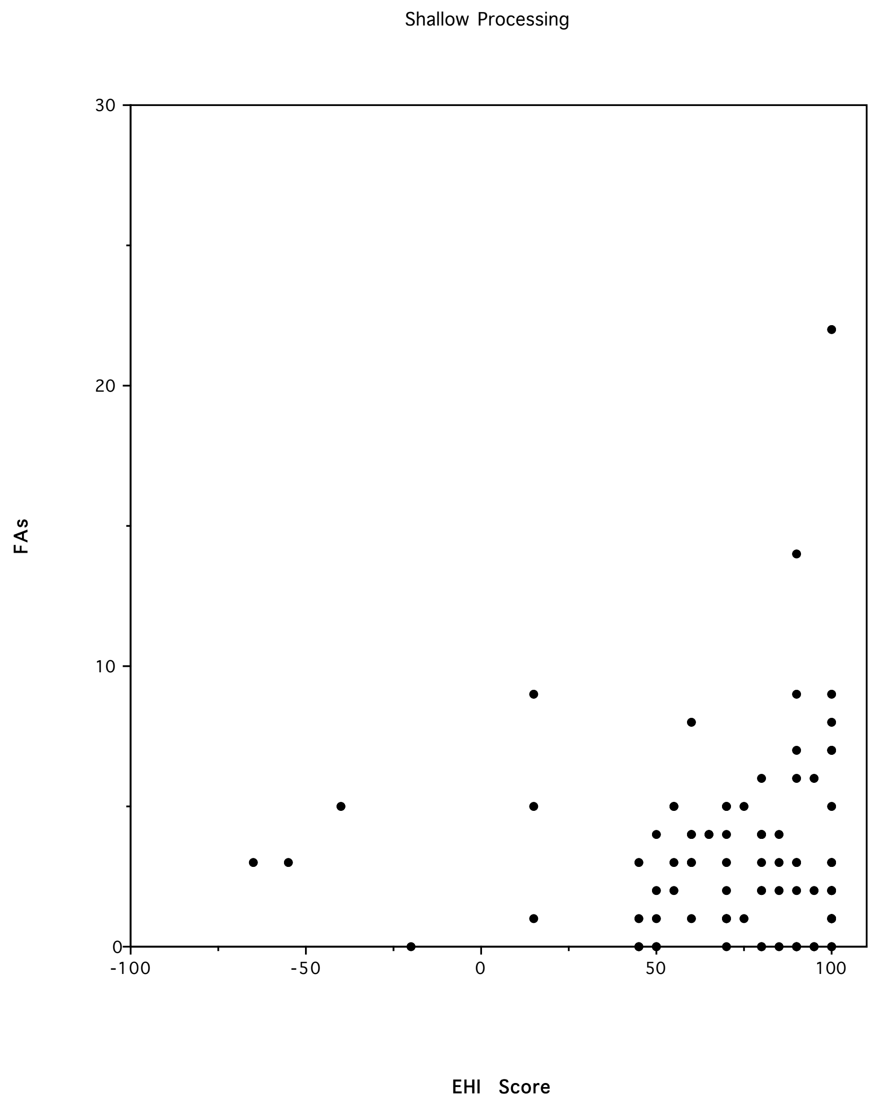


Figure 6. Scatterplot showing the relationship between number of words correctly recalled (i.e. hits) and strength of handedness in collapsed deep processing conditions.

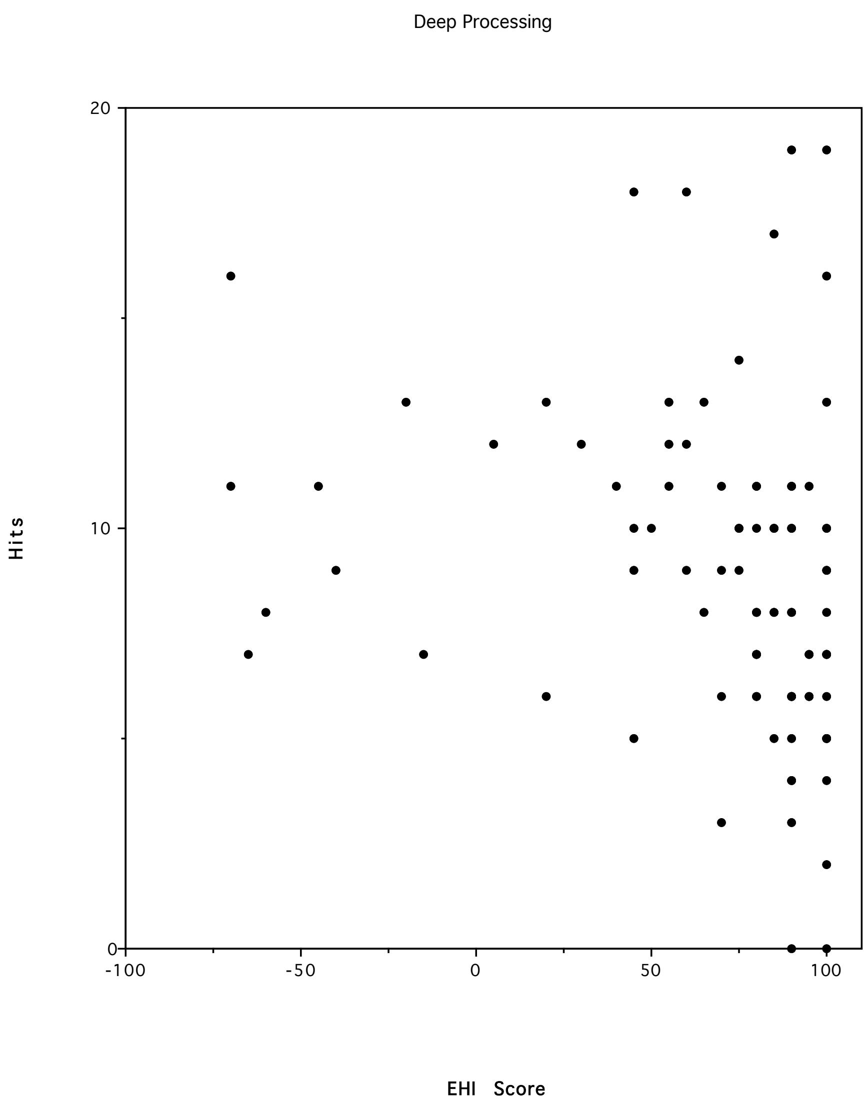
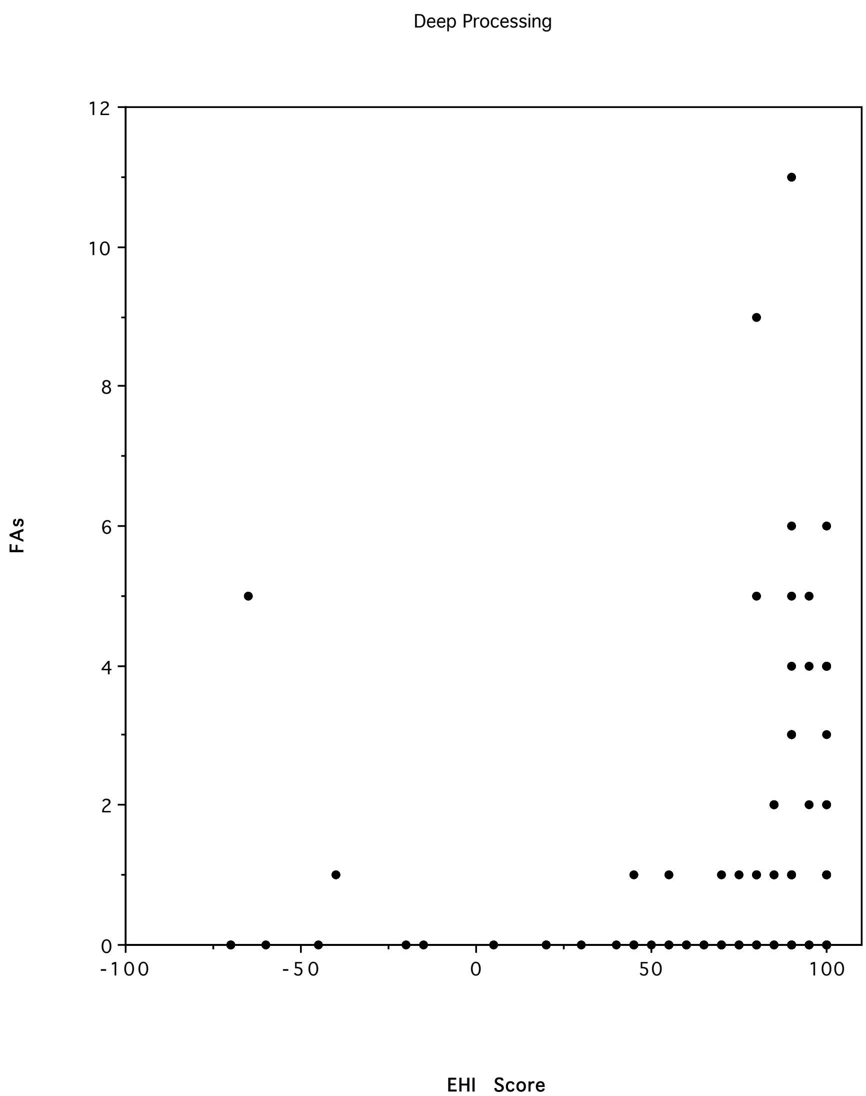


Figure 7. Scatterplot showing the relationship between number of words incorrectly recalled (i.e. false alarms) and strength of handedness in deep processing conditions.



Appendix A

Stimulus Material

Participants viewed a list of 24 words on a computer screen for 5 seconds each in random order. Yes/No questions were directly adapted from Craik and Tulving (1975) to represent three incidental encoding conditions (structural, phonemic, semantic). Structural questions asked if a word was in capital letters. Phonemic questions asked if the target word rhymed with another word. Semantic questions asked about the words meaning. The intentional encoding condition presented the words without asking any questions.

Word	Structural Question	Phonemic Question	Semantic Question
SPEECH	Capitals	lush	used for cleaning
brush	Capitals	each	a form of sound
cheek	Capitals	teak	a part of the body
FENCE	Capitals	tense	found in the garden
flame	Capitals	sour	used for cooking
FLOUR	Capitals	claim	something hot
honey	Capitals	funny	a type of food
KNIFE	Capitals	wife	a type of weapon
SHEEP	Capitals	stopper	a type of metal
copper	Capitals	leap	a type of farm animal
glove	Capitals	shove	something to wear
MONK	Capitals	crazy	a type of flower
daisy	Capitals	trunk	a type of clergy
miner	Capitals	liner	a type of occupation
CART	Capitals	start	a type of vehicle
CLOVE	Capitals	rove	a type of herb
ROBBER	Capitals	past	a part of a ship
mast	Capitals	clobber	a type of criminal
FIDDLE	Capitals	riddle	a musical instrument
CHAPEL	Capitals	bonnet	a written form of art
sonnet	Capitals	grapple	a type of building
witch	Capitals	rich	associated with magic
ROACH	Capitals	coach	a type of insect
brake	Capitals	shake	a part of a car

Appendix B

Edinburgh Handedness Inventory

Please indicate your preference in the use of hands for each of the following activities or objects by placing a check in the appropriate column.

	Always Left	Usually Left	No Preference	Usually Right	Always Right
Writing					
Drawing					
Spoon					
Open Jars					
Toothbrush					
Throwing					
Comb Hair					
Scissors					
Knife					
Striking a Match					

Are you female or male? M F

Is your mother left-handed? __________

Is your father left-handed? __________

Do you have any brothers or sisters who are left-handed? __________