A MOTOR THEORY OF LEARNING

by

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To my family and friends of the present and my ancestors of the past: thank you.

Abstract

This study investigates the possible differences between learning English pseudowords that are presented with or without handwriting movements. Based on the previous literature showing the learning benefits of handwriting *vs* reading new words- and neurophysiological evidence that suggests a system of neurons (mirror neuron system) can encode observed actions and elicit analogous motor responses in the observer - it is hypothesized that pseudoword learning will be facilitated when they are presented with handwriting movements. To this end, during a learning phase, pseudowords were visually presented. Following the learning phase, participants performed a recall phase consisting of a forced-choice task on statically presented pseudowords. Half of the pseudowords were new, while the other half consisted of an equal number of pseudowords presented in a handwritten or static way during the learning phase. EEG was recorded during both learning and recall phases. Measurement of EEG mu suppression was used as an index of mirror neuron activity during the learning phase. A cluster-randomization procedure was used to compare changes in Mu suppression during Handwritten and Static conditions. It was predicted that handwritten pseudowords would elicit larger Mu suppression than Static pseudowords. During the recall phase, learning was assessed using behavioral data on the forced-choice task, as well as the N400 component as an index of word familiarity. Results showed significantly more Alpha suppression for the Handwritten condition during the learning phase. In the recall phase, the Static condition showed more alpha suppression. Results suggest the Handwritten condition demanded more attentional processes than the Static condition during the learning phase. Consequently, the Handwritten condition needed less semantic processes to complete the forced-choice task of the recall phase.

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CHAPTER I

Introduction

The goal of the proposed study is to investigate whether there are any learning differences between stimuli that are presented with or without handwriting motions. Before discussing the details of the protocol, the relevant background literature concerning the benefits of handwriting, the link between visual perception and movement, and the link between writing and reading will be reviewed.

Benefits of handwriting

Handwriting is a valuable skill that is learned at an early age and is used for a lifetime. Good handwriting skill is a fundamental aspect of communication that is linked with numerous literacy skills such as reading speed (Beimiller et al., 1993), spelling (Berninger et al., 1992; Beimiller et al., 1993), speed of composing (Berninger and Fuller, 1992), and mathematics (Tarnopol and Feldman, 1987). These findings suggest that handwriting is deeply connected with skills that are important for everyday life and could have great significance within the context of an educational setting. In fact, a series of studies conducted by Simner (1982, 1986, 1989, 1991) provided evidence that handwriting difficulties in early childhood are an early indicator of subsequent academic problems. These studies found that the number of errors in forming letters was significantly correlated with teachers' evaluations of both children's readiness for the next grade and their progress in reading, phonics, language, and mathematics. In addition, a significant correlation was found between the number of errors in forming letters and class standing, end-of-the-year grades, and performance on a variety of standardized tests (e.g., Printing Performance School ReadinessTest; Keymath Diagnostic Arithmetic Test). Thus, this correlation provides evidence that writing skill correlates with abilities that do not necessarily involve motor movements.

Movement, Perception and the Mirror Neuron System

Our movements help organize our perceptions and contribute to our understanding of our environment (Viviani, 2002). In particular, movement may play an important role in action recognition, an ability that is fundamental for social behavior. There have been many hypotheses proposed to explain action recognition. One of these hypotheses that has recently found strong neurophysiological support is the “direct-matching hypothesis” (Buccino, Binkofski, & Riggio, 2004). The direct-matching hypothesis states that actions performed by others are recognized by mapping the observed action onto his/her own motor representation of the observed action. Additionally, action observation automatically activates in the observer the same neural structures involved in the actual execution of the observed action. This relationship of neural activity between action observation and action execution is hypothesized to allow the observer to understand what the actor is doing.

The mirror neuron system (MNS) provides neurophysiological support for the “direct-matching hypothesis” (Buccino, Binkofski, & Riggio, 2004). The MNS was first found in the rostral part of the ventral premotor cortex of macaque monkeys (Rizzolatti, 2005), an area that contains a motor representation of mouth and hand actions (Buccino, Binkofski, and Riggio, 2004). In this area, some neurons related to hand actions not only discharge when the monkeys execute specific goal-directed hand actions (e.g., grasping, holding, tearing, and manipulating objects) but also when they observe another monkey or person performing that same action. (Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). These neurons were named “mirror neurons” because the observed action seems to be “reflected,” like a mirror, in the motor representation for the same action of the observer. Since, other areas in the brain have been reported to show mirror neuron activity, including: primary motor cortex, Broca's area, supramarginal gyrus, and the premotor cortex (see Grezes and Decety (2001) for a meta-analysis of reported human cortical activity).

Congruency between the actual action and the observed action is needed in order for the mirror neurons to fire. In some instances, very strict congruencies may be required, and only the observation of an action which is identical to that coded motorically by the neuron can activate the system. More often, the needed congruency between action and observation is more flexible. For example, the observed and executed action need only match the goal of the action, rather than the specific single movements necessary to execute the action. Also, mirror neurons discharge only when a body part (i.e. a hand) interacts with an object (Buccino, Binkofski, & Riggio, 2004). Additionally, mirror neurons do not discharge when the observed action is simply mimicked, that is, executed in the absence of the object, nor do they discharge during the mere visual presentation of an object (Buccino, Binkofski, and Riggio, 2004). The discovery of these neurons has led to the hypothesis that the MNS plays an important role in both action recognition and motor learning (Jeannerod, 1994).

More recently, several studies suggested that humans also have mirror neurons (Rizzollatti, 2005). It should be noted that evidence for the human mirror neuron system is indirect, and there has not been any single-neuron recording comparable to the studies involving the macaque monkey previously described. Still, non-invasive neuroimaging techniques have yielded findings that suggest a similar MNS within humans. The first evidence for the human MNS was provided by Fadiga, Fogassi, Pavesi, and Rizzolatti (1995). In this study, single pulse transcranial magnetic stimulation (TMS) was delivered while subjects were observing an experimenter perform various hand actions. Motor evoked potentials were recorded from extrinsic and intrinsic hand muscles. Results showed that during hand action observation there was an increase of amplitude in motor evoked potentials recorded from those hand muscles which are normally recruited when the observed action is actually performed by the observer. Chao and Martin (2000) found that the visual presentation of objects that can be attributed to a specific action can also elicit activity in the premotor cortical area, even when no actual motor response is required from the subject In fact, many functional neuroimaging studies have revealed activation in the area of the human brain that is homologous to the monkey area F5 during action observation (Rizollatti and Craighero 2004). Interestingly, this human homologue is Broca's area (Buccino, Binkofski, and Riggio, 2004), an area classically associated with language.

Several studies also investigated changes in neural oscillations reflecting involvement of the mirror neuron system. Using magnetoencephalography (MEG), Hari *et al*. (1998) found neuromagnetic oscillatory modulation of the human precentral cortex both while participants manipulated objects and while they observed the objects being similarly manipulated. Cochin and colleagues (1999) found similar brain modulation between action execution and action observation while monitoring finger movements using the electroencephalogram (EEG). Results particularly showed the suppression of Mu rhythm (also known as the central, Rolandic, sensorimotor, wicket, or arceau rhythm) during both the observation and execution of various hand actions when compared to rest. The mu rhythm is an EEG oscillation with dominant frequencies usually located in the 8-13 Hz and 15-25 Hz bands (Pineda, 2005). These oscillations are limited to a brief duration (usually 500-2500 ms) and are recorded over human sensorimotor cortex in the absence of movement. Mu oscillations are maximal when an individual is at rest and are attenuated by voluntary movements, somatosensory stimulations, and imagined actions (Pineda, 2005; Pineda, Allison, & Vankov, 2000). Also, there is evidence that suggests there are different subtypes of mu rhythms (Pfurtscheller, Neuper, & Krausz, 2000). Data indicate that the lower frequency of the mu rhythm reflects a non-specific movement-type correlation, whereas the upper frequency shows a more focused and specific movement-type pattern. For example, upper frequency mu rhythms are clearly different between finger and foot movements, while lower frequency mu activity is similar. Moreover, increasing motion complexity also increases attenuation (Boiten, Sergeant, and Geuze, 1992). Additionally, hand dominance, handedness, and type of movement have an effect on mu activity as well (Stanecak and Pfurtscheller, 1996). Overall, the findings of mu rhythm research has led to the hypothesis that mu activity plays a role in translating "seeing" and "hearing" into "doing," which are necessary components for imitation learning. The use of mu suppression as an index for mirror neuron activity is also supported by functional correlations. Like mirror neurons, mu suppression correlates specifically to self-performed, observed, and imagined actions (Gastaut and Bert, 1954; Pineda *et al.*, 2000). Additionally, both mirror neurons and mu activity only respond to animate stimuli (Rizzolatti and Fadiga, 1998). Finally, mirror neurons (Buccino *et al.*, 2001) and mu activity (Pfurtscheller, Neuper, Flotzinger, and Pregenzer, 1997) seem to respond in a somatotopic manner. In short, these findings suggest that mu suppression can provide a reliable measure of mirror neuron activity.

There have also been studies that use behavioral paradigms to provide evidence for the MNS in humans. Using a reaction time paradigm, Brass, Bekkeering, Wohlshchlaeger, and Prinz (2000) investigated how movement observation could affect movement execution. The reaction time of executed finger movements were measured when movements were cued by either a symbol or by a finger movement. Participants were faster to respond when the finger movement was the relevant cue than when a symbol was used as the cue. Furthermore, the degree of similarity between the observed movement and the executed movement led to a faster execution of the observed movement. This shows strong evidence that observed movement has an influence on executed movement. Similarly, Craighero, Bello, Fadiga, and Rizzolatti (2002) found results for an observation-execution matching mechanism. After being presented pictures of hands being oriented in different positions, participants were instructed to grasp a bar. In one group, the picture displayed before the task depicted a hand in the final required hand position of the task. In another group, the picture displayed a hand in a position that was incongruent with the final required hand position of the task. Results showed faster responses when the hand orientation of the picture corresponded to that achieved by the hand at the end of the action.

To summarize, there is an extensive amount of evidence that supports the existence of a human mirror neuron system that is comparable to the mirror neuron system found in monkeys.

Handwriting and Reading: Shared Neural Network?

The link between perception and action has also been found for writing and reading skills. For instance, writing movements can help individuals with impairments such as pure alexia and agraphia (Anderson, Damasio, & Damasio, 1990). Patients with pure alexia who cannot visually recognize letters can sometimes recognize letters when they are asked to trace the outline of the letters with their fingers (Bartolomeo, Bachoud-Levi, Chokron, and Degos, 2002). These findings suggest that specific motor movements associated with each letter are adequate for letter recognition, even when the visual representation of that letter is ineffective, hence suggesting that letter representations are stored in both the visual and sensorimotor domains.

Also, the mistakes made by individuals with dysgraphia suggest that letters and the sensorimotor domain are coupled (Rapp & Caramazza, 1998). When writing, some patients commit letter substitution errors. For example, “table” is written as “fable.” When making a letter substitution error, the substitute letters usually resemble the target letter in stroke direction and length, and thus have a motoric similarity. This suggests that apart from a level of letter representation based on the visual letter form, there is also a representational level that contains the motor programs necessary to produce the required strokes of a given letter. In support of a letter-specific motor program of representation, the difficulties found in patients with dysgraphia are usually letter specific (James and Gauthier, 2006). Shape drawing that involves similar stroke sequences involved in letter writing is not affected by dysgraphia. A dramatic example of this is the patient that was reported to be able to write the number zero, but not the letter “O” (Delazer, Lochy, Jenner, Domahs, and Benke, 2002). These findings provide compelling evidence that speech evolved from gestural communication, and the “mirror” components represents the basic mechanism from which language evolved (Rizzolatti and Arbib 1998). Thus, the MNS may create a common, non-arbitrary link between communicating individuals. Relaying language information in a way that activates the MNS could prove more efficient than relaying language information in a manner that does not activate the MNS.

In line with the aforementioned studies, Longcamp, Anton, Roth, & Velay (2003) reported that the presentation of alphabetic characters activated a premotor zone in the left hemisphere of right-handed subjects and in the right hemisphere of left-handed subjects (measured using fMRI). Similarly, using fMRI, James & Gauthier (2006) found that letter processing automatically recruits a sensory-motor brain network. During a 1-back matching paradigm with letters, results showed that perceiving letters also engages the motor regions in the brain used while writing those letters; similarly, writing letters engages letter-specific visual regions of the brain.

This link between writing and reading letters that is observed in skilled adult readers may be an important aspect of reading acquisition. Longcamp *et al.* (2005) compared learning new words by typing and learning new words by handwriting. The study consisted of 76 preschool children, all of whom were screened for perceptual-motor development and manual dexterity. The participants were divided into two groups who were trained to copy letters of the alphabet either by hand or by typing them on a computer keyboard. After a three week learning session, participants were asked to point out the learned alphabet characters amidst distracter characters. Results revealed an improvement in letter recognition for the older handwriting group after the training session, where no difference between the sessions was observed for the older typing group. Handwriting training did not improve the performance of any participant under the age of fifty months. The authors suggested that this age-related difference could be explained by the younger participants' lesser cognitive development. It could be the case that the fine motor control involved in handwriting was not mature enough in the younger children for them to benefit from the motions conducted during the handwritten trials. Similarly, Cunningham and Stanovich (1990) found in an experiment using first graders that writing words improved spelling more than typing the words or arranging letter tiles to make the words. It is worth noting that the handwriting condition and the letter tile condition both involved fairly similar degrees of arm/hand movement. However, it was the specific arm/hand movements of actually writing words that facilitated learning the most.

While these findings suggest that there may be something special within the specific motions of handwriting which helps encodes the representation and spelling of words, they also suggest that handwritten words are processed differently than typed words. Handwriting is a good example of material that has the property of stimulus equivalence, in the sense that it has variable physical properties yet yields identical responses (Corcoran & Rouse, 1970). Indeed, human beings can recognize handwritten letters despite these characters having great variability and even unique idiosyncratic features which may have never before been seen. Nevertheless, these characters are recognized as if the highly specific letter forms have already been encoded within the reader. Since this is highly unlikely to be the case, it is plausible that readers employ certain strategies for the extraction of relevant information. This is in stark contrast to the perceptual task of recognizing typed text, which presents far less variability. As a result, reading handwriting is more laborious and time consuming when compared to reading typed print, presumably because it requires extra mental procedures to extract information.

To test whether there may be separate systems for perceiving different types of text, Corcoran & Rouse (1970) conducted three experiments in which participants were presented words for a fixed amount of time (median of 30 ms). After the exposure of a word, the participants were asked to call out the word verbally. Only words that were reported with complete accuracy were counted. However, if a word was mispronounced the participant was allowed to spell out the word to receive credit for that trial. The experiments measured the probability of recognizing tachistoscopically presented typed and handwritten words when (a) the types of words were presented in separate lists, and (b) when the types of words were presented together in mixed lists when subjects did not know what type of word to expect next in the sequence. In Experiment I, words were either handwritten lower case or typed lower case. Results from Experiment I showed that handwritten words were recognized significantly less than typed words. Experiment I also showed poorer performance for word recognition in the mixed condition when compared to the unmixed condition. It was suggested that the decrease performance in the mixed condition was due to the participants having to "switch" to the appropriate subroutine appropriate for recognition of the different word types, therefore taking up the limited time given to the participant to recognize the word. In Experiment II, two different handwritings were employed. Results from Experiment II showed no difference in performance between the two handwritings in both the mixed and unmixed conditions. In Experiment III, words were either typed lower case or typed upper case text. Results from Experiment III showed no difference in performance between the two text types. Importantly, the results from Experiments II and III supported the explanation to the difference in performance found in Experiment I. When following the proposition of "sub-routines" presented by the researchers, the parallel performance between the mixed and unmixed conditions in Experiment II and III are expected. The difference between the two conditions in those experiments did not require the participants to change their "sub-routines" for recognition. For Experiment II, despite there being two separate handwritings, the conditions required the same mental process for recognition; thus, there was no significant difference in performance. In experiment III, results suggest that the lower case typed words and upper case typed words were also handled by the same mental process. Therefore, participants had enough time to properly recognize the words during the short fixed-time trials.

To summarize, the aforementioned studies suggest that handwritten words and typed words are perceived differently. Given the differences in perception and processing demand between handwritten and typed words, it is possible that the different word types could also have varying impact on learning.

The Proposed Study

The current study seeks to investigate the learning differences between viewing handwritten and static-visual words. To this end, participants will be presented with videos of English pseudowords presented either statically or when being handwritten and they will be asked to learn those new words. All of the experimental Handwritten and Static pseudowords will be presented twice during the Learning phase of the experiment. After the Learning phase, participants will perform a forced-choice memory task in order to compare retention of Handwritten words and Static words. Based on the literature, it is proposed that seeing pseudowords being handwritten should be more efficient than viewing the same information presented statically because it will activate the MNS to a higher degree than words presented statically. To test this hypothesis, electroencephalography (EEG) will be used to monitor potential activity from the mirror neuron system. In particular, if seeing pseudowords being handwritten engages the MNS more than words presented statically, their presentation should be associated with larger Mu rhythm suppression.

In addition to analyzing changes in neural oscillation to monitor the activity of the MNS, Event-Related Potentials (ERPs) will be recorded as an index of pseudoword learning. Out of the many established ERPs that are obtained, the N400 is the measure that will be used in this study. The N400 was initially found to be elicited when a word is semantically incongruous within a particular sentence context (Kutas & Hillyard, 1980). The amplitude of the N400 has since been found to be modulated by several factors such as word frequency and word repetition (Besson, Kutas, & Van Petten, 1992; Rugg, 1990; Van Petten & Kutas, 1990). In particular, the N400 decreases with the repeated presentation of low frequency words (Rugg, 1990) and pseudowords (Rugg & Nagy, 1987). Similarly, in an “old/new” discrimination task, Rugg and Nagy (1988) showed that newly presented words elicited larger N400 than words that had been previously presented. In short, the N400 decreases as a function of word familiarity; words that are unfamiliar will elicit a higher N400 than words that are familiar. Likewise, the present study will use the N400 as a measurement of word familiarity during the repeated presentations of experimental words as well as during the memory test. Regarding the proposed project, since viewing words being handwritten is expected to facilitate learning, the N400 amplitude should decrease faster with the repetition of Handwritten pseudowords than Static pseudowords during the Learning Phase. In addition, during the memory task, the N400 elicited by pseudowords that were presented handwritten should be smaller than the N400 elicited by pseudowords that were presented statically, which would suggest a higher familiarity effect for Handwritten pseudowords than Static pseudowords.

CHAPTER II

Methods

Participants

A total of 9 participants (3 females, mean age of 26.8 years) volunteered for the study. All were right-handed native speakers of English with normal or corrected to normal vision and no known neurological problems. The data of two participants were discarded due to noisy EEG data. IRB approval to conduct the study was obtained from the MTSU Institutional Review Board and written consent was obtained from the participants prior to the start of the experiment.

Stimuli

Ninety-six disyllabic English pseudowords ranging between four and five letters were used for the experiment (the complete list of words used in the study can be found in the Appendix.

For the “handwritten” condition, the pseudowords were filmed being written down on a dry-erase board with a black marker. The video is oriented such that the white space of the dry-erase board fills the entire screen, and only the lower quarter of the human arm performing the handwriting task is visible. The hand appears from the bottom right corner of the screen and writes the pseudoword in the middle of the screen. Once the word is written, the hand exits the frame through the lower right corner of the screen. The written word stays on the screen for 1 second after the hand leaves the frame. All videos include the same hand and are uniform in both lighting and recording angle.

In the static-visual condition, the words were presented using the Arial font. Each static word duration matched the duration of their handwritten counterpart. The font size (32 points) and letter spacing of the static visual words were matched as close as possible to the words in the handwritten condition (See Figure 1 for examples of stimuli).

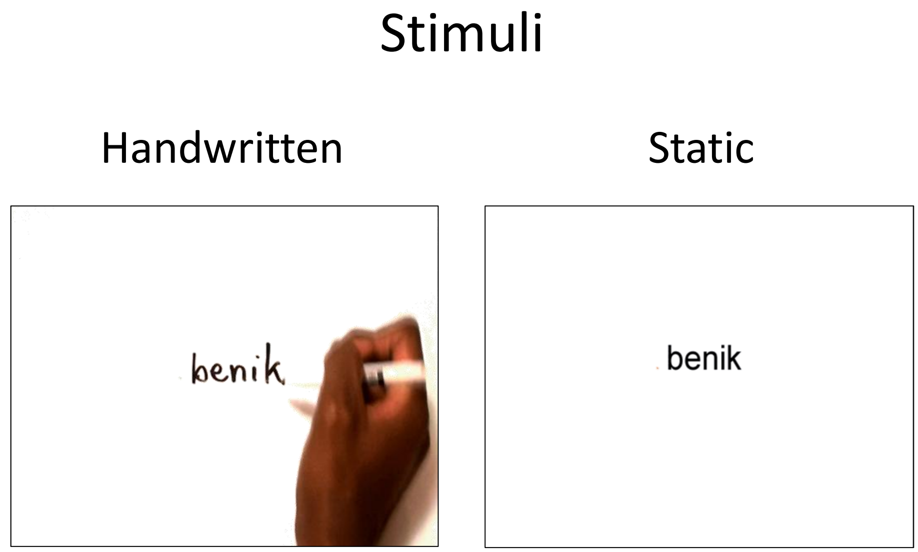

Figure 1. Screenshots from the Handwritten and Static conditions.

Protocol

The Learning phase contained videos of the two experimental conditions (Handwritten and Static) presented on a computer screen. Thirty-two pseudowords for each condition were displayed a total of two times. In addition, 32 filler pseudowords were used as distracters and were presented only one time. All stimuli were presented in a semirandom order. The sequence for each trial consisted of the presentation of a fixation cross in the center of the screen with a variable duration of 1600 to 1750 ms, followed by a 5-second-long video of a Handwritten word or a Static word.

Learning gains were measured using a computerized forced-choice task. The test consisted of pseudowords presented consecutively in the middle of a computer screen. Half of the pseudowords were old experimental items (half from the Handwritten condition and half from the Static condition) while the other half were distracter words never presented before (See the Appendix). For each word, participants were asked to decide as fast and accurately as possible whether or not it was previously presented during the Learning phase. This was done using a two-button response. Participants pressed Button 1 for words they believe are from the Learning phase and Button 2 for new words.

Each experimental session began with practice trials to familiarize participants with the task and train them to blink during the interstimulus interval. The entire experimental session lasted approximately 2 hours.

Data Acquisition

During both the memorization phase, and the forced-choice task, the electroencephalogram (EEG) was recorded continuously from 128 Ag/AgCL electrodes embedded in sponges in the Hydrocel Geodesic Sensor Net (EGI, Eugene, OR, USA) placed on the scalp with Cz at the vertex, connected to a NetAmps 300 high-impedance amplifier, using a MacBook Pro computer. Data was referenced online to Cz. The frequency of acquisition was 500Hz, and impedances were kept below 50 kOhm. EEG preprocessing was carried out with NetStation Viewer and Waveform tools. The EEG was filtered offline with a bandpass of 0.1 to 100 Hz. The data were then re-referenced offline to the algebraic average of the left and right mastoid sensors. In order to detect the blinks and vertical eye movements, the vertical and horizontal electrooculograms (EOG) was also recorded. Data time-locked to the onset of the experimental items were segmented into epochs of 5500 ms, starting with a 500 ms baseline prior to the onset of the words and continuing 5000 ms post-word-onset. Trials containing movements, ocular artifacts or amplifier saturation were discarded. Individually for each subject, ERPs were computed by averaging together the EEG segments for each condition at each electrode site relative to a 100 ms pre-stimulus onset. For the statistical analysis, electrodes were grouped into eight regions of interest on the scalp (left anterior-frontal; right anterior-frontal; left centro-frontal; right centro-frontal; left temporal; right temporal; left parieto-occipital; right parieto-occipital).

Data Analysis

Behavioral data for correct responses and reaction time were analyzed using T-Tests. For the reaction times, only the data for correct responses were used in the analysis.

Mean amplitudes of the ERPs were computed between 300 and 600 ms following the onset of the recall stimuli relative to a 100 ms pre-stimulus baseline. Mean ERP amplitudes were compared between the two experimental conditions using analyses of Variance (ANOVA). Stimulus Type (static *vs.* handwritten) and Scalp Region (left anterior frontal; left mid-frontal; left centro-temporal; left parieto-occipital; right anterior frontal; right mid-frontal; right centro-temporal; right parieto-occipital; See Figure 2) were used as within-subjects factors. All p values were adjusted with the Greenhouse–Geisser epsilon correction for nonsphericity when necessary.

Spectral decomposition [1] of the EEG data during the learning phase and Time Frequency (TF) analysis of the EEG during the recall phase were performed using the FieldTrip software (Oostenveld, Fries, Maris, Schoffelen, 2011) in order to compare changes in neural oscillations during Handwritten and Static pseudowords. For both the Spectral data and the TF data, statistical significance between Handwritten and Static conditions was determined using the cluster-randomization procedure implemented in Fieldtrip. A 500 ms prestimulus baseline was used for the spectral and TF analyses. Analysis focused particularly on the 8-10 Hz frequency band that is associated with both alpha and Mu activity.

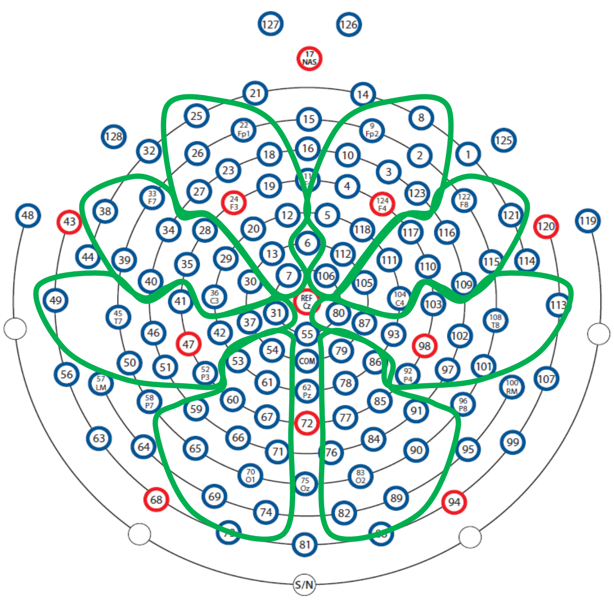

Figure 2. Electrode layout and Scalp Regions used for the statistical analysis of the ERPs (green contours).

[1] For the learning phase, because of the intrinsic differences in both stimulus structure and presentation between the static and handwritten conditions, spectral information averaged over the whole stimulus time period was analyzed rather than the time dependent frequency spectrum.

CHAPTER III

Results

Learning Phase

Statistical analysis of the EEG spectra revealed two significant clusters of activity. The first significant cluster ($p < 0.0001$) was a decreased low-alpha activity (8-10 Hz) for the Handwritten condition compared to the Static condition. This cluster was located over the centro-frontal area of the scalp (See Figure 3).

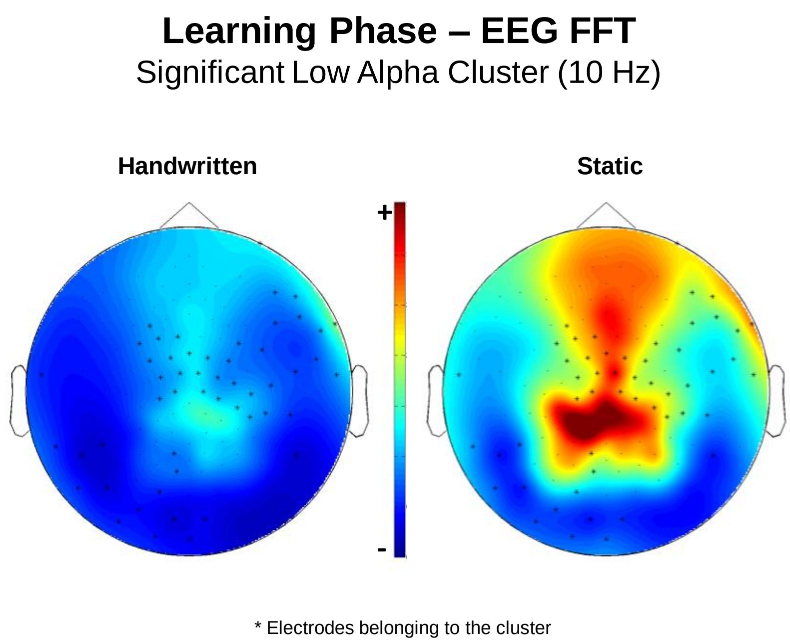

Figure 3. Topographic display of significant results for 10 Hz activity.

The second significant cluster ($p < 0.0001$) was a decreased high-alpha activity (10-12 Hz) for the Handwritten condition compared to the Static condition. This cluster was broadly distributed over the scalp (See Figure 4).

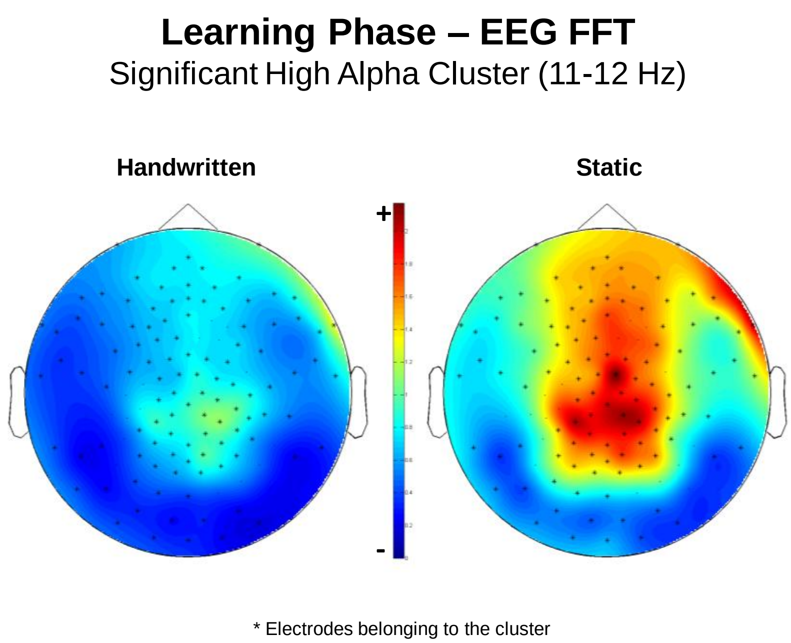

Figure 4. Topographic display of significant results for 11-12 Hz activity

Recall Phase

Behavioral data

Behavioral data showed no significant differences in percentage of correct responses between the Static (*M* = 82.31, *SD* = 4.70) and Handwritten (*M* = 81.26, *SD* = 5.59) conditions [*t* (10) = -.352, *p* = .732]. Significant differences in percentage of correct responses were found between Filler and Experimental items, *t* (16) = -2.279, *p* = .037.

There was no significant difference in response time between Static (*M* = 1037.06, *SD* = 451.61) and Handwritten (*M* = 1042.39, *SD* = 426.84) conditions [*t* (155) = .069, *p* = .945]. Significant differences in response time for correct answers were found between the Handwritten and Filler conditions, [*t* (218) = -2.397, *p* = .017] as well as between the Static and filler conditions [*t* (219) = -2.454, *p* = .015].

EEG data

ANOVAs performed on the ERP data did not reveal any significant main effect of Stimulus Type [*F*(1,6) = 0.02 ; *p* = 0.897] or Stimulus Type x Scalp Region interaction [*F*(7,42) = 1.31 ; *p* = 0.269] in the 300-600 ms latency range (See Figure 5).

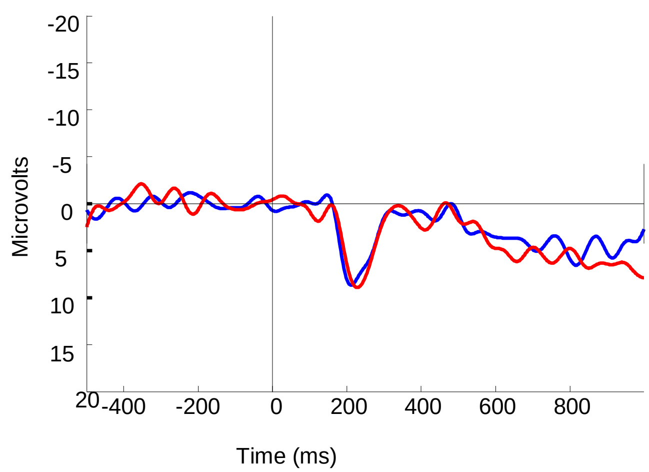

Figure 5. Grand-average for 7 participants showing the EPR elicited by old handwritten pseudowords (red trace) and old static pseudowords (blue trace) at the electrode Cz.

Statistical analysis of the time-frequency data revealed two significant clusters. The first was a significant positive low-alpha cluster (p = 0.017) between 1 and 372 ms following the onset of the stimuli. This cluster was located over the fronto-central area of the scalp and exhibited higher activity for the Handwritten condition when compared to the Static condition (See Figure 6).

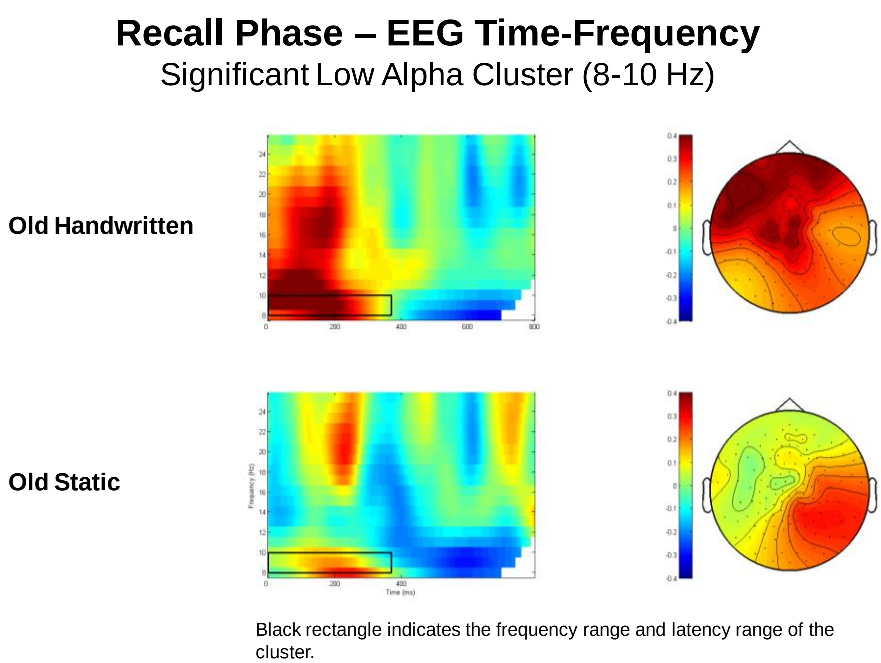

Figure 6. Time-frequency analysis of low-alpha cluster (8-10 Hz). Significance was found between 1 - 372 ms, p = 0.017.

The other significant cluster was a high-alpha cluster (p =0.007) between 2 and 780 ms for the Handwritten condition compared to the Static condition. This cluster was located over the centro-frontal scalp region (See Figure 7).

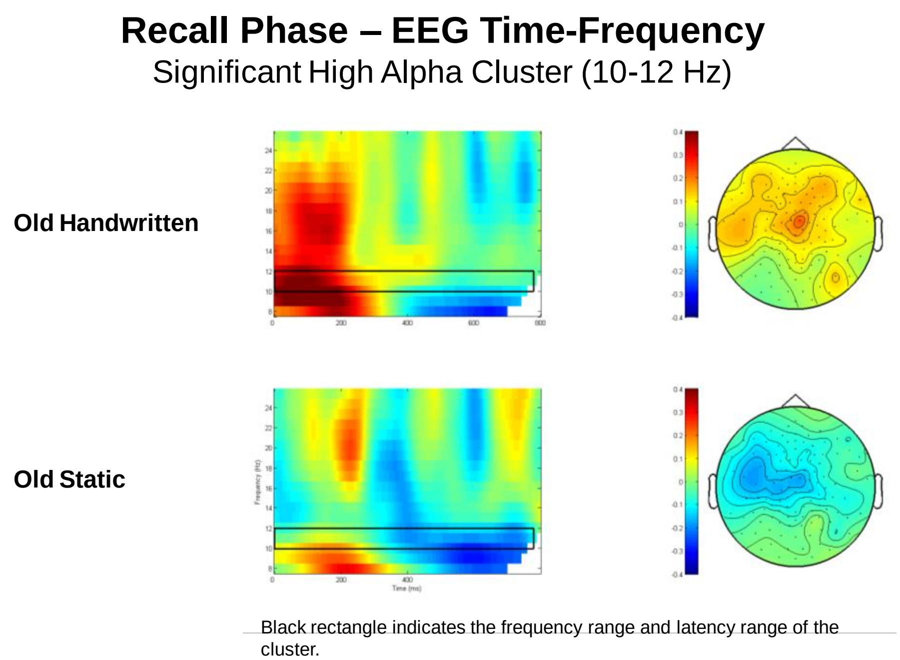

Figure 7. Time-frequency analysis of low-alpha cluster (10-12 Hz). Significance was found between 2 - 780 ms, p =0.007.

CHAPTER IV

Discussion

The results can be summarized as follows. During the learning phase, the Handwritten condition showed higher attenuation of low and high alpha activity than the Static condition. The recall phase displayed a reversed pattern, with significantly higher attenuation of low and high alpha activity for the Static condition than the Handwritten condition. In contrast, during the learning phase, no significant difference was found between old static and old handwritten stimuli for the behavioral data nor for the ERP data.

Cognitive Processes Underlying Alpha Rhythm

It was hypothesized that the Handwritten stimuli would attenuate the mu rhythm significantly more than the Static stimuli. The Rolandic mu rhythm, frequency-wise undistinguishable from the alpha rhythm, denotes a rhythm of different localization and significance. In particular, whereas the alpha rhythm is classically observed in the posterior region of the scalp, but can also be found over the frontal and temporal regions (Niedermeyer, 1997), the mu rhythm is found only over the somatosensory areas. The observed significant EEG activity was found in clusters that overlapped regions known for both mu and alpha activity. Thus, the cognitive correlates of both alpha and mu will be discussed.

Learning Phase

There was less activity in the 8-10 Hz frequency range over the centro-frontal region of the scalp for the Handwritten condition when compared to the Static condition.

It is well known that alpha attenuation reflects a state of active cortical information processing (Klimesh, Doppelmayr, Schwaiger, Auinger, and Winkler, 1998). The alpha attenuation is a local phenomenon that occurs over task-relevant brain areas. Thus, occipital alpha rhythms can be considered idling rhythms of the visual system and parietal alpha rhythms as idling rhythms of sensorimotor systems (Pfurtscheller, Stancak, and Neuper, 1996). In addition, several authors have proposed that different sub-ranges of frequency within Alpha correspond to distinct processes. The lower alpha band (8-10 Hz) attenuation may reflect attentional processes whereas the upper alpha band attenuation would underlie stimulus-related semantic processes (Klimesch, Schimke, Doppelmayr, Ripper, Schwaiger, and Pfurtscheller, 1996).

Given the lack of differences in both behavioral responses and ERP data between Handwritten and Static conditions, this significant decrease in activity in the low-alpha band suggests the Handwritten condition simply required more attentional processes. This seems intuitive when taking the difference in presentation between the stimuli into account. The hand movements presented in the Handwritten condition could have simply elicited more attentional processing than the stationary typed letters of the Static condition. There was also a significant decreased high-alpha for the Handwritten condition when compared to the Static condition. This significant decrease in the high-alpha band suggests more semantic processing for the Handwritten condition. This increase in semantic processing could be due to the aforementioned attentional advantage of the Handwritten condition.

The Handwritten condition's significantly higher attenuation of the 8-12 Hz activity could also be interpreted as Mu suppression. Mu suppression is observed when an individual conducts voluntary movements, experiences somatosensory stimulation, or views the motor movements performed by other individuals (Boiten, Sergeant, and Geuze, 1992; Pineda *et al.*, 2000). Mu suppression is also used as an index of the mirror neuron system (Buccino *et al.*, 2001; Pfurtscheller, Neuper, Flotzinger, and Pregenzer, 1997). Thus, the present finding may indicate that the Handwritten condition activated the mirror neuron system to a higher degree than did the Static condition.

Recall

Neither behavioral nor ERP data revealed any significant difference between Handwritten and Static conditions. It is worth noting, though, that participants responded with an overall correct response rate of 79.18 %, In addition, both the Handwritten and Static conditions showed significantly faster reaction times than the Filler condition, suggesting that the participants gained some familiarity with the experimental pseudowords during the learning phase. Taken together, the high rate of correct responses and faster reaction times for experimental items suggest that the recall task may have been too easy for the participants, thus offsetting any potential benefit of one mode of presentation onto the other. Increasing the number of experimental items to be learned is one way to make the task more challenging and possibly reveal differences between the two conditions. Alternatively, because the recall test was performed immediately following the learning phase, the possibility remains that difference in learning manifest after a longer retention period. One possible way to address this issue would be to increase the delay between learning phase and recall phase (for instance, by performing them a week apart).

There was significant decreased 8-10 Hz activity over the fronto-central region of the scalp for the Static condition compared to the Handwritten condition. This finding suggests that increased attentional resources were needed to make a decision regarding the Static condition. It is important to note that “Handwritten” and “Static” items in the recall phase were both presented as a static text image. The items were, however, presented in a different font-type and color than the ones used in the static condition during the learning phase. This resulted in the static items having a highly similar appearance between the learning and recall phases (especially when considering the difference in appearance of the Handwritten condition between the learning and recall phase). However, correct responses for words from the Handwritten condition required less cortical activity. This finding highlights the possibility that the mode of presentation in the two conditions during the learning phase had differing effects on the neural encoding of the pseudowords (with the Handwritten condition showing an advantage).

There was also significant decreased activity in the 10-12 Hz cluster over the centro-frontal scalp region for the Static condition compared to the Handwritten condition. This finding suggests another favorable result for the Handwritten condition, as high-alpha activity has been linked to semantic processing. Thus the decreased semantic processing needed to make the correct responses in the recall task suggest a more developed encoding of the Handwritten condition (Klimesch, Schimke, Doppelmayr, Ripper, Schwaiger, and Pfurtscheller, 1995).

Giving the recall phase a Mu interpretation is less clear. The higher attenuation of the 8-12 Hz activity of the Static condition suggests higher Mu suppression. This is problematic because the recall phase presented both conditions in a static manner, so it can be assumed there was no motor component present that could attenuate Mu. Furthermore, the increased Mu suppression of the Static condition is not only in direct opposition of the findings in the learning phase (where the presentation differences between conditions should have differentially affected Mu) but also in direct opposition of the literature. Taken together, the present findings favor the alpha interpretation.

Conclusion

The present study suggest that a relatively short exposure to handwritten movements is enough to trigger stronger changes at the neural level than static presentation, even before any difference can be evident at the behavioral level. Static presentation of to-be-learned words may not be the optimal option for learners. If this is the case, adjustments may need to be considered in areas such as education. The classroom is increasingly departing from traditional handwritten chalkboard lectures and opting for more static PowerPoint-type presentations. Although using PowerPoint does present many advantages to convey abstract concepts (through video or picture for instance), this study suggests that the static presentation of linguistic material may not be as effective as the written presentation through hand motions.

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APPENDICES

Appendix A

Psuedowords (tested)		Psuedowords (filler)	Forced-choice distracters
COTI	HEBER	BOLAR	ALMIT
IBOT	PUNDY	TOBIL	BEFIN
ROGA	AMCAS	FENO	NETA
VUSY	HISER	UBAGE	GEVEL
GADY	MURVY	REFET	BLAZA
RUVY	FODER	SMOTY	MOGUS
TASY	ORSOT	DIBIL	CORAX
EMIL	CULLY	ULEM	DORON
OMER	PELER	PABIC	GURRO
INGA	DOPPY	IBIN	PUYER
LOMIC	ARVER	UNAL	CAKIS
TAVER	HUNEP	BAPLE	GARAT
MEVER	ABLOR	ANFY	COJEC
FAXIN	PITOL	UNGO	LUBIC
ASCAN	SAREL	JIRUS	PUMIN
CAPY	TIDER	OWDAN	LATUM
ARBIN	RAVIE	CODIK	DIVUS
MURU	GOLAN	HEBA	ENPEL
PIVEN	SEDEL	BINER	EXFO
JINTO	EDLLE	RAKAR	JATAL
ROLAR	BENIK	MIKIT	VORAY
TAMBO	RATO	MASTI	LUMOS
SOVOR	HULIN	WONER	CONNA
RASTO	ECAY	FAMBA	GORGO
PAMAD	RUDIC	OLGOM	GRATI
AGISH	TIVEL	SILAT	GRIPA
BAGIN	BULY	KODIM	GLOVA
TUSY	GOTER	MINEL	LUBO
DODAL	BIMY	URGIT	GLARA
TIGIC	CHOBY	ELBAS	ESPA
RIDAL	FIPLE	HYBAN	KOBEN
LUPON	AMSUM	HEVA	LURA

Appendix B

MIDDLE TENNESSEE STATE UNIVERSITY

April 2, 2012

Jaymes Durriseau, Cyrille Magne, Nicole Brunas
Protocol Title: "Electrophysiological study of the impact of teaching method on new word learning"
Protocol Number: **12-275**

Dear Investigator(s),

The MTSU Institutional Review Board, or a representative of the IRB, has reviewed the research proposal identified above. The MTSU IRB or its representative has determined that the study poses minimal risk to participants and qualifies for an expedited review under the 45 CFR 46.110 Category 4 and 7.

Approval is granted for one (1) year from the date of this letter for 40 participants.

According to MTSU Policy, a researcher is defined as anyone who works with data or has contact with participants. Anyone meeting this definition needs to be listed on the protocol and needs to provide a certificate of training to the Office of Compliance. **If you add researchers to an approved project, please forward an updated list of researchers and their certificates of training to the Office of Compliance (c/o Emily Born, Box 134) before they begin to work on the project.** Any change to the protocol must be submitted to the IRB before implementing this change.

Please note that any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918.

You will need to submit an end-of-project form to the Office of Compliance upon completion of your research located on the IRB website. Complete research means that you have finished collecting and analyzing data. **Should you not finish your research within the one (1) year period, you must submit a Progress Report and request a continuation prior to the expiration date.** Please allow time for review and requested revisions. Your study expires **April 2, 2013**.

Also, all research materials must be retained by the PI or faculty advisor (if the PI is a student) for at least three (3) years after study completion. Should you have any questions or need additional information, please do not hesitate to contact me.

Sincerely,

Emily Born

Emily Born
Research Compliance Officer
Middle Tennessee State University