Only Three Fingers Write, But The Whole Brain Works[1]: Is the pen mightier than the word?

Audrey van der Meer & F.R. (Ruud) van der Weel

Department of Psychology, Developmental Neuroscience Laboratory

Norwegian University of Science & Technology (NTNU)

Trondheim, Norway

Audrey.meer@svt.ntnu.no; Ruudw@svt.ntnu.no

Abstract— **Electroencephalogram (EEG) was used in young adults to study brain electrical activity as they were *writing* or *describing* visually presented Pictionary™ words using a keyboard, or as they were *drawing* the same words using a stylus. Analyses of temporal spectral evolution (TSE, time-dependent amplitude changes) were performed on EEG data recorded with a 256-channel sensor array. Our results showed that in the *drawing* condition, brain areas in the parietal and occipital regions showed Event Related Desynchronizing (ERD) activity in the theta/alpha range. These findings are consistent with existing literature and are often reported to provide an optimal background for learning. In the *describe* condition, beta/gamma range activity in the central and frontal regions could be observed, especially during the early stage of cognitive processing. Such activity is often associated with the involvement of higher cognitive, top-down processes and the creation of ideas.**

It was concluded that because of its obvious benefits for sensory-motor integration and learning, hand written note-taking is introduced back into the classroom. Sensory-motor information for the control of (pen) movement is picked-up via the senses and because of their involvement they leave a wider mark on establishing pathways in the brain resulting in neural activity that governs all higher levels of cognitive processing and learning. Therefore, rich sensory-motor experiences seem to facilitate learning. With several new stylus technologies available on the market today this may be the way to go to have an electronic record of one's notes, while also having the benefit of being able to integrate the information as it comes in via the senses and is subsequently processed in the various parts of the brain through movement.

Keywords: Pictionary™; Keyboard vs longhand writing; EEG; Power %; Note taking; ERD; ERS; TSE; Microsoft; Tablet; Laptop.

[1] Adapted from the medieval scribe: «Only three fingers write, but the whole body works».

I. INTRODUCTION

The use of laptops in classrooms is controversial. Many teachers believe that computers (and the Internet) serve as distractions, detracting from class discussion and student learning. Conversely, students often self-report a belief that laptops in class are beneficial. Even when they admit that laptops are a distraction, they believe the benefits outweigh the costs. However, even when distractions are controlled for, laptop use might impair performance by affecting the manner and quality of in-class note taking. There is a substantial literature on the general effectiveness of note taking in educational settings, but it mostly predates laptop use in classrooms. Prior research has focused on two ways in which note taking can affect learning: encoding and external storage (see DiVesta & Gray, 1972; Kiewra, 1989). The external-storage hypothesis touts the benefits of the ability to review material (even from notes taken by someone else). The encoding hypothesis suggests that the processing that occurs during the act of note taking improves learning and retention. Note taking can be generative (e.g., summarizing, paraphrasing, concept mapping) or non-generative (i.e., verbatim copying). Verbatim note taking has generally been seen to indicate relatively shallow cognitive processing (Craik & Lockhart, 1972; Kiewra, 1985). The more deeply information is processed during note taking, the greater the encoding benefits (DiVesta & Gray, 1973; Kiewra, 1985). Studies have shown that verbatim notetaking predicts poorer performance than non-verbatim note taking, especially on integrative and conceptual items (Aiken et al., 1975; Bretzing & Kulhavy, 1979; Igo, Bruning, & McCrudden, 2005; Slotte & Lonka, 1999). Traditional laptop use facilitates verbatim transcription of lecture content because most students can type significantly faster than they can write (Brown, 1988). Thus, typing may impair the encoding benefits seen in past note-taking studies. However, the ability to transcribe might improve external-storage benefits.

There has been little research directly addressing potential differences in laptop versus longhand note taking, however, a recent study by Mueller and Oppenheimer (2014) addressed the issue directly. In their first study, college students watched one of five TED Talks covering topics that were interesting but not common knowledge. The students, who watched the talks in small groups, were either given laptops (disconnected from Internet) or notebooks, and were told to use whatever strategy they normally used to take notes. The students then completed three distractor tasks, including a taxing working memory task. A full 30 minutes later, they had to answer factual-recall questions (e.g., "Approximately how many years ago did the Indus civilization exist?") and conceptual-application questions (e.g., "How do Japan and Sweden differ in their approaches to equality within their societies?") based on the lecture they had watched. The results revealed that while the two types of note-takers performed equally well on questions that involved recalling facts, laptop note-takers performed significantly worse on the conceptual questions. The notes from laptop users contained more words and more verbatim overlap with the lecture, compared to the notes that were written by hand. Overall, students who took more notes performed better, but so did those who had less verbatim overlap, suggesting that the benefit of having more content is canceled out by mindless transcription. The authors suggest that it may be that longhand note takers engage in more processing than laptop note takers, thus actively selecting important information to include in their notes. Surprisingly, the authors saw similar results even when they explicitly instructed the students to avoid taking verbatim notes, suggesting that the urge to do so when typing is hard to overcome. The authors also found that longhand note takers still beat laptop note takers on recall one week later when participants were given a chance to review their notes before taking the recall test. Once again, the amount of verbatim overlap was associated with worse performance on conceptual items. From these results is seems that using traditional pen-and-paper is preferable over traditional laptop use when taking notes, however, it is hard to imagine that a mass of people will actually be switching back to using notebooks. Yet, there are several new stylus technologies out there, and those may be the way to go to have an electronic record of one's notes, while also having the benefit of processing information as it comes in, rather than mindlessly transcribing it.

The present study was designed with this in mind. In a series of experiments it was investigated whether there are any underlying electro-physiological differences using electroencephalogram (EEG) that could explain the differences underlying traditional (keyboard) versus more modern (stylus technology) writing. The above encoding hypothesis will be central in the explanation of the results, especially with respect to the differences between generative (deep encoding) and non-generative writing (shallow encoding). Therefore, we designed an experiment based on the popular family game of Pictionary™ (Hasbro, 1985) involving three different conditions: (a) *writing* (visual words on keyboard involving shallow encoding); (b) *describing* (visual words on keyboard involving deep encoding); and (c) *drawing* (visual words with stylus involving deep encoding). It was investigated which parts of the brain are active during these three different conditions.

II. METHOD

A. *Participants*

We recruited 20 students (12 female) between 21-25 years from our local University campus (NTNU, Trondheim, Norway). Seventeen provided sufficient artefact-free data for the analyses. All participants were given the Edinburgh handedness test (Oldfield, 1971) to determine dominant hand use. We only accepted right-handed participants to the study. All participants gave their informed written consent and had the liberty to withdraw from the experiment at any time. Participants were after the experiment rewarded with a US $20 cinema ticket.

B. *Experimental stimuli and paradigm*

An ASK M2 projector was used to project the target words onto a rectangular display (108 cm wide, 70.5 cm high) at a constant 80 cm in front of the participant (see Figure 1). The width and height of the display subtended angles of 68° and 47°, respectively, with image resolution of 593 pixels/m at a refresh rate of 60 Hz. Psychological software tool, E-prime, was used to generate 20 different Pictionary™ words generated from the medium difficulty section of the Pictionary™ app "Game Words" developed by "The Game Gal" at (https://www.thegamegal.com). The 20 selected words were presented three times (n=60) in a random order. For each trial participants were instructed to either (a) typewrite the word repetitively separated by a single space using their right index finger on the laptop tablet keyboard, (b) describe the word using their right index finger on the laptop tablet keyboard, and (c) draw the word using their right hand with the stylus on a second identical laptop tablet (see Figure 2 for examples). There were two laptop tablets used in the experiment to minimize unnecessary movement in between trials that could cause artifacts in the data. One laptop tablet was attached to a keyboard and the other one came with a stylus. The laptop tablets were made available by Microsoft, Europe for the duration of the experiment. We used two identical Microsoft Surface Pro 4 laptop tablets; 256 GB/Intel Core i5 – 8 GB RAM with Type Cover and Surface-pen attached. Laptop data produced by the participants were stored in Microsoft OneNote for offline analyses.

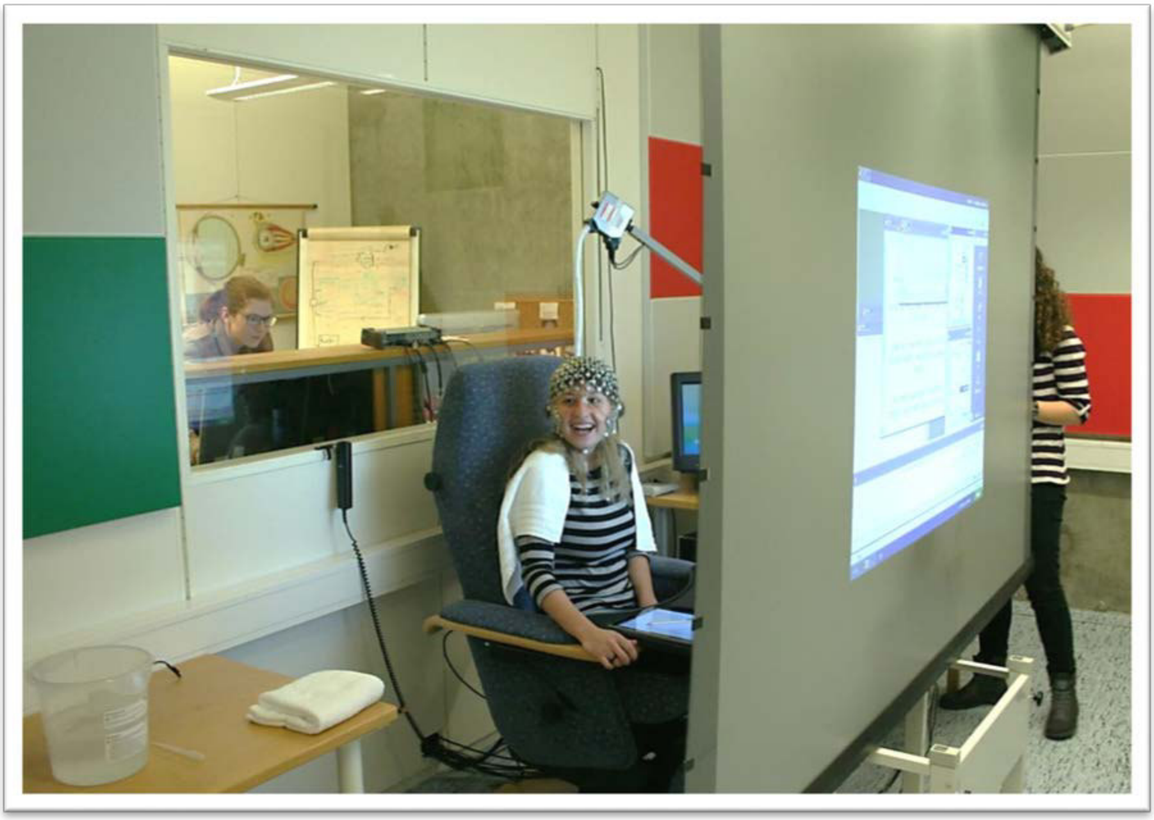

Figure 1. Experimental set-up with a participant wearing the Geodesic Sensor Net. On the large screen right in front of the participant Pictionary™ words were projected which either had to be typewritten, described, or drawn on one of the two laptop tablets in front of the participant using the keyboard (for writing and describing) or the stylus (for drawing). Word presentation and EEG recordings were continuously monitored from the adjacent control room.

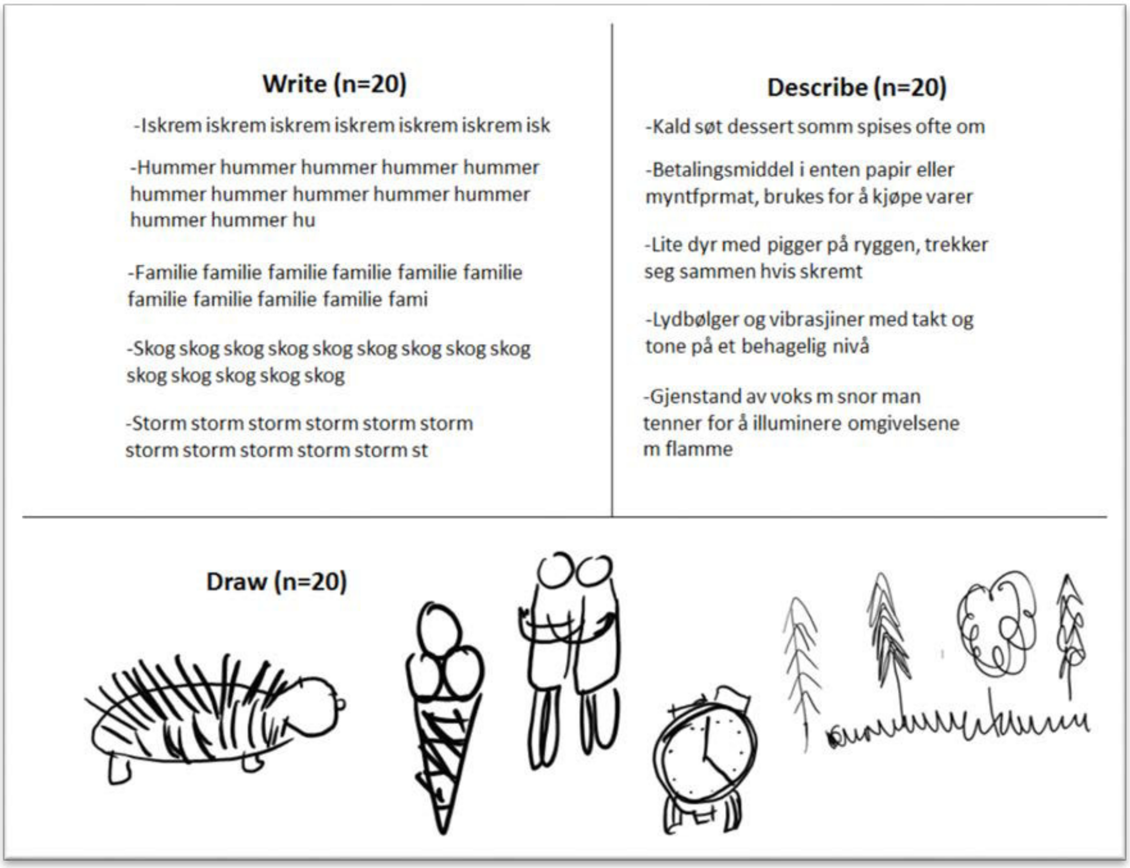

Figure 2. Illustrative sample of Pictionary™ responses produced by the participants: written down and described using the laptop tablet keyboard, or drawn on the laptop tablet with a stylus.

C. *EEG Data acquisition*

EEG activity was recorded with a Geodesic Sensor Net (GSN) 200 (Tucker, 1993; Tucker, Liotti, Potts, Russell & Posner, 1994) consisting of an array of 256 sensors that were evenly distributed on the participant's head (see Figure 1). A high-input EGI amplifier connected to the net ensured amplification of signals at maximum impedance of 50 kΩ as recommended for an optimal signal-to-noise ratio (Budai et al., 1995; Ferree et al., 2001; Picton et al., 2000). Net Station software on a separate computer recorded amplified EEG signals at a sampling rate of 250 Hz. To track off-line the behavior of the participants during the experiments, digital videos were recorded with two cameras positioned at different angles in front of the participants. Recorded data were subsequently stored for off-line analyses.

D. *Procedure*

Participants usually arrived several minutes prior to the experiment. The necessary information for the signing of the consent form was made available and the Edinburgh

handedness test was administered. In the process, an assistant measured the participant's head circumference for the correct size selection of the net. After soaking the appropriate net in a saline electrolyte to optimize electrical conductivity, it was partially dried and mounted on the head of the participant. After the net was mounted, the participant was moved into a dimly lit experimental room that was separated with a transparent glass partition from a control room where two assistants operated the computers necessary for data acquisition. The participant was positioned in front of the screen (see Figure 1). The net was connected to the amplifier and the impedance of the electrodes was checked. If necessary, contact of electrodes was improved by adding saline electrolyte to the electrodes or simply adjusting their position.
The experimental session began immediately after the participant’s electrode impedance was approved. The words were presented in a random sequential order on the screen for a fixed number of trials, 60 per participant: 20 Pictionary™ words in the *write* condition; the same 20 words in the *describe* condition; and the same 20 words in the *draw* condition. Each word appeared on screen for 25 s with 5 s intervals. Participants were instructed to move as little as possible during the 5 s recording time to avoid artifacts caused by eye, head and body movements. Data acquisition was carried out in one block and lasted for about 45 minutes. However, word presentation was paused in the event of a participant indicating a need to the control room.

III. ANALYSES

A. *Data pre-analyses*

EEG raw data were analysed with Brain Electrical Source Analysis (BESA) research software version 6.1. As an initial pre-processing step, recordings were segmented with the Net Station software and exported as raw files with the appropriate auxiliary files attached. Averaging epoch was from −300 ms to 5000 ms at a baseline definition of −300 ms to 0 ms. The notch filter was set at 50 Hz to remove line interference from the recorded data. A low cut-off filter was set at 1.6 Hz to remove slow drift in the data, while a high cut-off was set at 75 Hz. Artefact-contaminated channels and epochs resulting from head or body movements were excluded from further analyses or their signals estimated using spherical spline interpolation (Perrin et al., 1989; Picton et al., 2000). Using the recorded visual feed of each participant from the video recordings, trials where participants were not fully concentrated on the task were excluded from further analyses. In scanning for artifacts, threshold values for gradient and low signal were set at 75 μV and 0.1 μV, respectively, while maximum amplitude was at

200 μV. Manual artifact correction designed to separate brain activity from artefacts using spatial filters was applied to correct for physiological artefacts caused by blinking or eye movements (Berg & Scherg, 1994; Fujioka, Mourad, He, & Trainor, 2011; Ille, Berg, & Scherg, 2002). In rare instances where a manual selection could not be accomplished, an automatic artefact correction with preset default values (150 μV and 250 μV for horizontal and vertical electro-oculogram amplitude thresholds, respectively) was applied to define and explain artefact topographies by principal component analysis (Ille et al., 2002; Zanotelli, Santos Filho & Tierra-Criollo, 2010). The mean number of accepted trials for all participants was 56 (*SD* = 3) more or less evenly distributed over the three experimental conditions.

Time-frequency analyses in brain space

Time-frequency analyses were performed in brain space using multiple source dipoles that modelled the main brain regions of interest (see Figure 3). The wide distribution of focal brain activity at scalp surfaces due to the nature of dipole fields and the smearing effect of volume conduction in EEG means that scalp waveforms have mixed contributions from underlying brain sources, and thus measuring oscillatory activity on scalp surface electrodes may not be ideal. Optimal separation of brain activity was therefore achieved using source montages derived from a multiple source model where source waveforms separated different brain activities (see Scherg & Berg, 1991). The regional sources model used covered frontal, central, temporal, and parietal areas, as well as occipital areas. These sources are believed to be active in the processing of perceptuo-motor stimuli in our experiment (Probst et al., 1993; Zeki et al., 1991). In analysing these sources, a 4-shell ellipsoidal head model (Berg & Scherg, 1994; Hoechstetter et al., 2004) was created for each participant and the source dipoles were inserted while the artefact-corrected coordinate files were appended.

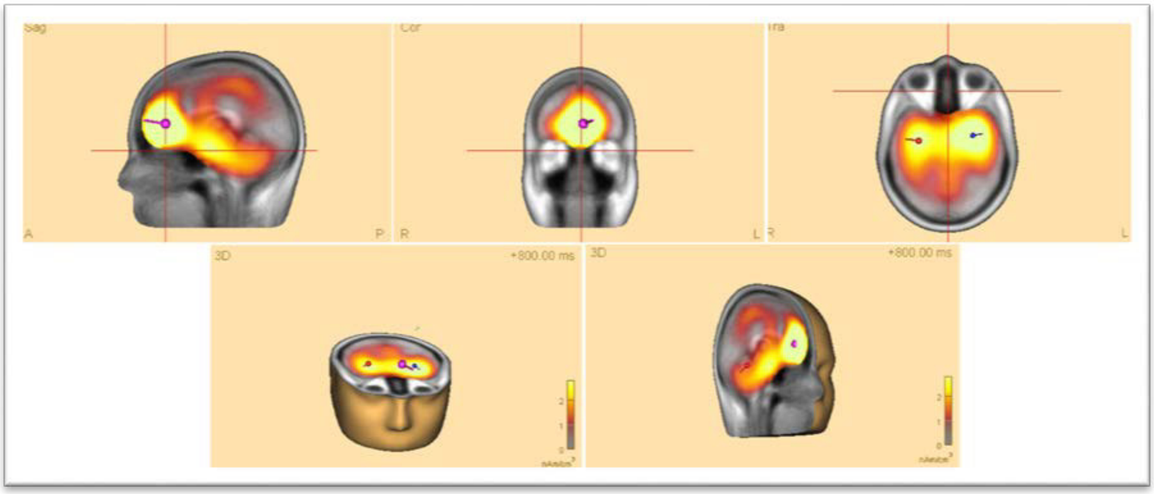

Figure 3. Head model of a typical (female) participant showing 4 dipoles (location and direction of electrical current) in associated brain regions in frontal, central, temporal, parietal, as well as occipital areas. The signal magnitude reflects the estimated source activity.

Time-frequency displays (see Figure 4), representing the change in amplitude over time (TSE, temporal spectral evolution), were generated from the single trials by averaging spectral density amplitudes over trials. In this way, each graph displayed plotted the spectral amplitude density of one montage channel over time and frequency normalized to the baseline for each frequency (Hoechstetter et al., 2004; Pfurtscheller, Neuper, & Mohl, 1994; Pfurtscheller et al., 1996). To focus only on induced oscillatory brain activity, average evoked response signals were removed from the single trial time series before computing a TSE. Comparisons between the three conditions *write*, *describe*, and *draw* were computed for each participant. TSE displays were limited between frequency cut-offs of 4–40 Hz, while frequency and time sampling were set at 1 Hz, 40 ms.

A separate statistical program (BESA statistics 2.0, BESA GmbH) was used to test the probability of significance in amplitude values and frequency ranges between each of the three experimental conditions in the TSE data for all participants. An average of TSE statistics for each participant could then be computed such that significant time-frequency ranges could be used as a guide in finding maximum oscillatory activities in each individual TSE. A combination of permutation tests and data clustering (see Bullmore et al., 1999; Ernst, 2004; Maris & Oostenveld, 2007) was employed in the statistical tests to address the multiple comparisons problem. Here, data clusters that showed a significant effect between conditions were assigned initial cluster values that were the sum of all *t*-values of all data points in each cluster. Using a paired *t*-test, these initial cluster values were passed through permutation and assigned new cluster values such that the significance of the initial clusters could then be determined based on the distribution of the calculated cluster values assigned to each initial cluster after permutation. Cluster alpha (the significance level for building clusters in time and/or frequency) was set at 0.005, number of permutations (determined randomly without repetition) at 10,000 and frequency cut-offs kept the same as stated above with epochs set from −300 to 5000 ms. Further statistical comparison of TSEs between our three experimental conditions for all participants was performed so as to compute probability maps to test for significant differences in the TSEs when comparing conditions (see Figure 5). Here, Bonferroni procedure and permutation tests as described by Simes (1986) and Auranen (2002) were used and applied to each set of time samples belonging to one frequency bin so as to correct for multiple testing. Frequency cut-offs and sampling points were maintained as stated above.

IV. RESULTS

Time-frequency responses Figure 4 displays the results of the TSE maps from a typical (female) participant across brain regions of interest for the three experimental conditions *write*, *describe*, and *draw*. Brain regions of interest were located in frontal (FpM; FL; FM; FR), temporal (TAL; TAR; TPL; TPR), central (CL; CM; CR), parietal (PL; PM; PR) and occipital (OpM) areas of the brain. The signal magnitude (Power %) reflects the estimated neural activity in the various brain regions compared to baseline (-300ms-0ms) activity. Increased spectral amplitude (induced synchronized activity, ERS: Event Related Synchronization) is shown as red coloured contours (more dominant in the *write* and *describe* conditions) with decreased spectral amplitude (induced desynchronized activity, ERD: Event Related Desynchronization) shown as blue coloured contours (more dominant in the *draw* condition).

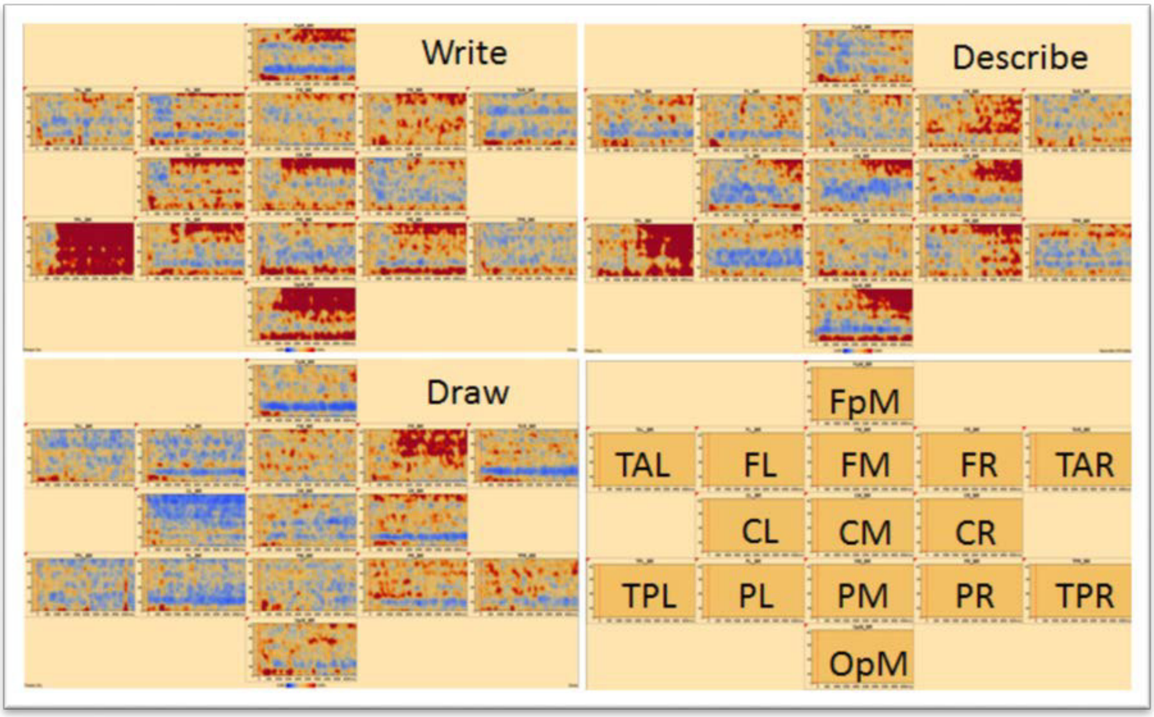

Figure 4. Time-frequency displays of a typical (female) participant showing associated brain regions in frontal (FpM; FL; FM; FR), temporal (TAL; TAR; TPL; TPR), central (CL; CM; CR), parietal (PL; PM; PR) and occipital (OpM) areas of the brain. The signal magnitude (Power %) reflects the estimated neural activity in the various brain regions during the experimental conditions write, describe, and draw compared to baseline (-300ms-0ms) activity. Note that red areas indicate synchronization (ERS) and blue areas indicate desynchronization (ERD) of associated brain activity.

Figure 5 displays the differences in results of the permutation tests for the average of *all* participants between the conditions *describe* and *draw*. Only the differences between *describe* and *draw* are reported here because there were no clear differences found between *write* and *describe*. The permutation results (of clusters where the null-hypothesis is rejected i.e. data are not interchangeable) showed five significant negative clusters (in blue), in the central and right-frontal areas. The permutation results also showed four significant positive clusters (in red), in the parietal and occipital areas. Blue areas in the right frontal and central areas appeared to be dominated by activity in the beta (12-20 Hz) and gamma (20-34 Hz) range that was more prevalent during the earlier (ideation) parts of cognitive processing. Red areas in the parietal and occipital areas appeared to be dominated by activity in the theta (3-8 Hz) and alpha (8-13 Hz) range that was more prevalent during the execution stage of cognitive processing (see also Table 1 for details).

Cluster ID	**p-value**	**Cluster value**	**Mean for *describe***	**Mean for *draw***	**Start Time**	**End Time**	**Start Frequency**	**End Frequency**
CM	0.00023	-1763	-0.29	0.01	200	2900	11	36
PL	0.00032	1699	0.25	-0.25	1050	5000	4	16
PR	0.00385	1103	0.34	-0.27	1500	5000	4	13
OpM	0.00826	902	0.38	-0.26	1700	4600	4	9
FM	0.01380	-785	-0.29	0.02	1250	3400	16	30
FR	0.01402	-781	-0.27	0.06	400	2600	16	33
CR	0.02079	-687	-0.12	0.35	600	1850	13	31
PM	0.03831	537	0.45	-0.28	2950	5000	4	10
TAR	0.04594	-509	-0.18	0.17	350	1450	16	29

Table 1. Permutation test results for nine significant clusters in decreasing order.

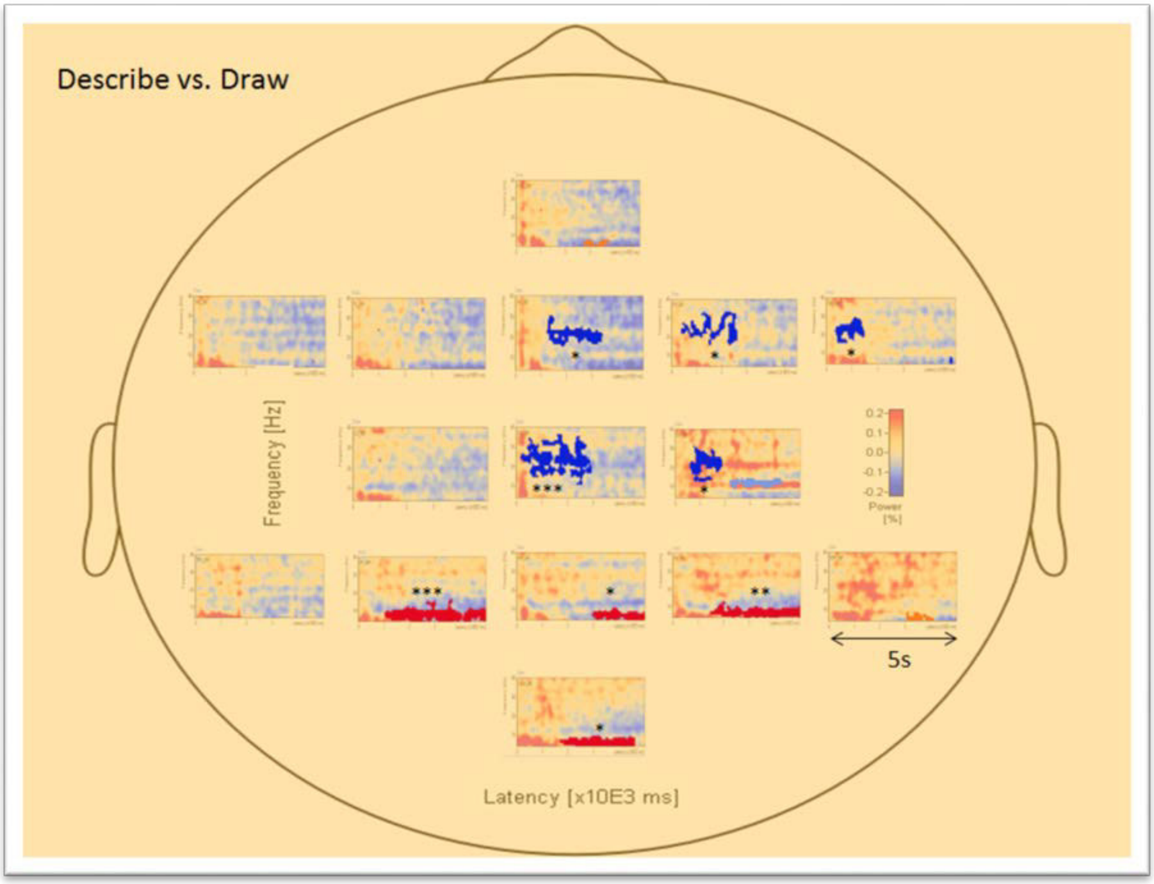

*Figure 5. The average visualization of significant (*** p=<.0005; ** p=<.005; * p=<.05) data clusters in the various sources of interest when the describe condition is compared to the draw condition. Centre and (right) frontal areas represent pre-motor, motor, and areas of creativity, whereas parietal and occipital areas represent sensory-motor integration and visual interpretation. Blue colours represent negative clusters, red colours represent positive clusters. Each area in the central and frontal region is dominated by activity in the beta (12-20 Hz) and gamma (20-34 Hz) range, especially during the early parts of cognitive processing (ideation phase). Areas in the parietal and occipital region are dominated by activity in the theta (3-8 Hz) and alpha (8-13 Hz) range, almost for the entire drawing duration of the trials (execution phase).*

V. Discussion

In this experiment, high-density EEG was used in adult participants to study brain electrical activity as a function of writing, describing, and drawing a visually presented Pictionary™ word in an attempt to explain the differences underlying traditional (keyboard) *writing* versus modern (stylus technology) *drawing*. TSE analyses were used to investigate whether there were differences in brain activity in participants when they were using a laptop tablet keyboard versus using a laptop tablet pen. No clear differences between *writing* and *describing* Pictionary™ words were found in the analyses so we concentrated fully on differences between *describing* and *drawing* words. A direct comparison between these conditions is interesting because both include a similar ideation phase (thinking how to describe/draw the seen word) but a different execution phase (typing on a keyboard versus drawing on the screen).

Beta/gamma range activity in the frontal and central regions

Our results showed that the ideation phase was most prominent in the *describe* condition where high-frequency oscillations (beta/gamma) were present during the first 2-3 s of each trial. This activity may be associated with higher cognitive thought processes as to how to describe the seen word in the best possible way. Especially the right pre-frontal areas of the brain have been associated with creativity in other studies (Srinivasan, 2007; Schwab, 2014; Jaarsveld, 2015) and could explain high activity in those parts of the brain during the *describe* condition. However, neuroscientific studies into the neural mechanisms underlying creativity seem inconsistent, but there appears to be some evidence that EEG beta/gamma power is particularly sensitive to various creativity-related demands involved in creative ideation. Beta/gamma increases during creative ideation could reflect more internally oriented attention that is characterized by the absence of external bottom-up stimulation and, thus, a form of top-down activity (Marr, 1982). We should keep in mind, however, that the activity in the frontal and central areas found in this experiment was observed to also include induced *synchronized* activity (ERS), i.e. increased synchrony within the neural network. With gamma-oscillations found <35 Hz this may actually indicate less active cortical areas with decreased excitability of the neurons. Namely, when groups of neurons display such coherent synchronized activity, an active processing of information is rather unlikely and it may be assumed that the corresponding networks are in a deactivated state (Pfurtscheller & Lopes da Silva, 1999). So, the actual contribution of the frontal areas showing high frequency gamma oscillations in our results remains unclear.

No such high-oscillatory activity was observed in the *drawing* condition suggesting that finding out how to draw a seen word does not include a well-defined ideation stage, but is more characterized by an ongoing continuous process where the drawing unfolds as-one-goes-along.

Theta/alpha range activity in the parietal and occipital regions

Our results further showed that the execution phase was more prominent in the *draw* condition where low-frequency oscillations (theta/alpha) in the parietal and occipital areas were present during almost the entire trial apart from the first second or so. This activity may be associated with visually processing of the seen Pictionary™ word and the subsequent sensory-motor integration during the entire stages of cognitive processing. Moreover, the activity present in the parietal and occipital areas also included induced *desynchronized* activity (ERD) within the associated neural networks involving a decrease of spectral peak and amplitude attenuation resulting in higher activation of cortical areas and increased excitability of the involved neurons. Pfurtscheller and Lopes da Silva (1999) argued that induced desynchrony can be interpreted as an electrophysiological correlate of activated cortical areas involved in processing of sensory or cognitive information or production of motor behaviour. An increased and/or more widespread desynchrony could be the result of the involvement of a larger neural network or more cell assemblies in information processing and learning. Factors contributing to such an enhancement of desynchronization are increased task complexity (Vilhelmsen, Van der Weel, & Van der Meer, 2015), more efficient task performance (Agyei, Holth, Van der Weel, & Van der Meer, 2015; Boiten et al., 1992; Dujardin et al., 1993; Klimesch et al., 1996a; Sterman et al., 1996) and/or more effort and attention as needed in patients, elderly, or lower IQ subjects (Defebvre et al., 1996; Derambure et al., 1993; Neubauer et al., 1995, 1999). It is interesting to note that, in general, about 85% of cortical neurons are excitatory, with the other 15% being inhibitory (Braitenberg & Schüz, 1991). Inhibition in neural networks is, however, very important, not only to optimize energy demands but also to limit and control excitatory processes. Klimesch (1996) suggested that synchronized band rhythms during mental inactivity (idling) may be important to introduce powerful inhibitory effects, which could act to block a memory search from entering irrelevant parts of neural networks.

Thus, desynchronized activity (ERD) in the parietal and occipital areas of the brain may have its beneficial effects on learning, particularly when it was shown to occur in the rather deep structures of the brain (c.f. red dipole, Figure 3) close to the limbic system, including the hippocampus, traditionally a brain area known for its association with learning.

Furthermore, recent studies suggest that theta-band oscillation and desynchronization (ERD), as shown in our results, may also be involved in mechanisms underlying sensory-motor integration. Specifically, the neural circuitry underlying the production of oscillation and desynchronization in the limbic system and associated structures functions in the capacity of providing systems with continuous control information on their performance (Bland & Oddie, 2001). Thus, because of its rich sensory-motor nature the involvement of *drawing* may have a beneficial effect on the learning process in general. Sensory-motor information for the control of movement is picked up via the senses and because of their involvement they leave a wider mark on establishing pathways in the brain resulting in neural activity that governs all higher levels of cognitive processing and learning. Therefore, rich sensory-motor experiences seem to facilitate learning. In general, rich learning experiences will combine images that include shape patterns (occipital), tones and words (temporal and frontal), emotional connections (from the limbic system), and not the least movements (sensory-motor areas and the cerebellum). Whenever movements are included as part of learning more of the brain gets stimulated, which results in the formation of more complex neural networks.

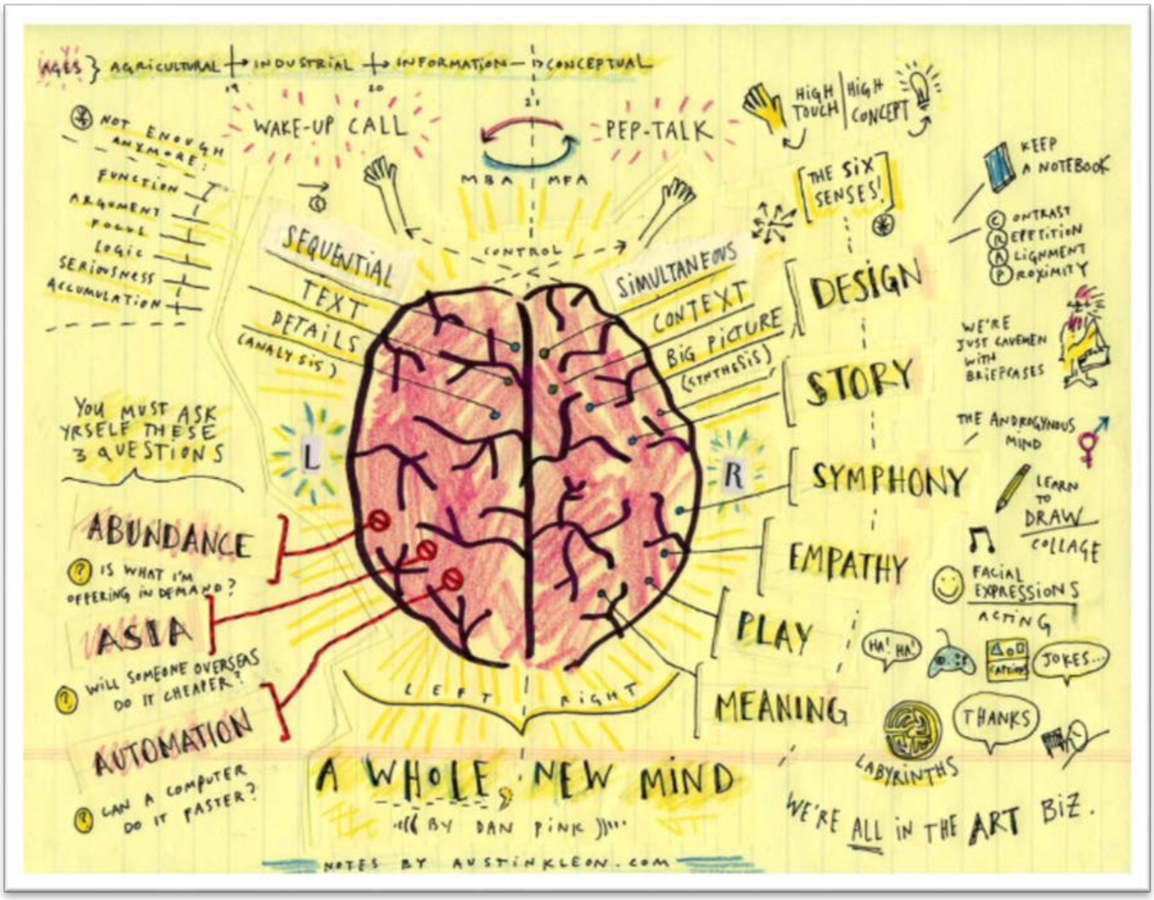

Figure 6. Example of visual notetaking by Austin Kleon, who describes himself as a "writer that draws", demonstrating how to capture ideas pairing pictures with words.

In conclusion, Mueller and Oppenheimer (2014) found evidence that lecture notes written in longhand were superior to verbatim keyboard notetaking as regards learning outcome, especially in recall studies. The authors interpreted their results that longhand note taking involves a deeper processing of lecture material: the encoding hypothesis suggests that the processing that occurs during the act of longhand note taking improves learning and retention. In the present study, we found direct electro-physiological evidence to support these findings. We found that during the *drawing* condition, using the laptop tablet stylus, relevant brain areas (parietal/occipital) showed *desynchronized* activity (ERD) in the theta/alpha range. Existing literature suggests that such findings provide an optimal background for learning. During the *describe* condition, using the laptop tablet keyboard, we found *synchronized* activity (ERS) in the central and frontal regions during the ideation stage of the trials. This activity is often associated with the involvement of higher cognitive processes and the creation of ideas. However, since this activity is highly synchronized its relation to the learning processes remains unclear.

From the Mueller and Oppenheimer (2014) study together with our results a clear recommendation might be to introduce handwritten notes back into the classroom in order to optimize the learning process. However, it can be argued that *drawing* a Pictionary^{tm} word onto a laptop tablet may not be the same as taking more elaborate longhand notes from a lecture. This may be true, but it can be argued that fundamental electrophysiological processes as measured in our experiment are similar especially when sensory-motor pen movements are included into the note taking process. However, to be sure about this generalization more studies are needed in which keyboard typing and stylus notetaking are directly compared during a (short) lecture. In addition an extra condition may be introduced which involves visual notetaking (see Figure 6) in which ideas are captured by combining pictures and words. Here is would be interesting to find out, from the EEG records, whether there are fundamental differences in brain processing when lecture notes are taken using the keyboard, the stylus, or using the stylus and visual notetaking combined.

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Brain research: key information

The power of the pen in learning

Executive summary

The power of the pen is proven by a scientific study showing that digital notetaking by hand is superior to using a laptop with a keyboard. This is the conclusion from brain research conducted by the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway, and scientists Audrey van der Meer and Ruud van der Weel. The scientists now recommend that notetaking by hand should be re-introduced in classrooms worldwide. The research underlines the power of the pen in learning, at a time when many students are exclusively using keyboard input for note-taking and learning.

Background

- Research carried out by Audrey van der Meer & F.R. (Ruud) van der Weel, Department of Psychology, Developmental Neuroscience Laboratory, Norwegian University of Science & Technology (NTNU), Trondheim, Norway
- Aim of the research was to see if there is evidence that different parts of the brain are utilized when using a pen on a tablet computer versus typing on the keyboard

Results

- This study presents the first electrophysiological evidence that the brain behaves differently when writing/drawing using a pen versus typing on a keyboard.
- Our results indicate that when comparing students drawing a word as opposed to describing the word, not only were different parts of the brain active but the brain was also active in a special way that makes it more prone to learning.
- When writing or drawing by hand, different parts of the brain were active, especially the motor and sensory areas. In addition, these parts of the brain were active during the whole drawing period in a way that is known to be beneficial to learning.
- When describing the word using the keyboard, central and frontal parts of the brain were active, but only for a short period during the ideation phase when participants were thinking how best to describe the word. Especially the right-frontal areas of the brain have been associated with creativity in other studies.
- It is recommended that, because of its obvious benefits for sensory-motor integration and learning, handwritten notetaking is introduced back into the classroom.
- Stylus technology – like Surface Pen – provides a means to have an electronic record of one's notes all in one place, while also having the benefit of integrating sensorimotor information as it comes in via the senses and is subsequently processed in the various parts of the brain through hand movement.

Method/Process

- The research method has been used in a number of previously published scientific journals and specifically by van der Meer and van der Weel.
- For the research project, Trondheim University recruited 20 (12 female and 8 male students between the ages of 21-25. Van der Meer and van der Weel's previously published papers on EEG have all used approximately 20 subjects.

- The participants used 2-in-1 Surface Pro 4 devices to complete different tasks and, with advanced recording of brain signals, using over 250 sensors, the scientists were able to analyse brain activity.
- The participants were part of an experiment designed on the popular family game, Pictionary™ (Hasbro, 1985). 20 selected words were presented three times in a random order.
- For each trial participants were instructed to either:
    a) Typewrite the word repetitively separated by a single space using their right index finger on the laptop tablet keyboard,
    b) Describe the word using their right index finger on the laptop tablet keyboard, and
    c) Draw the word using their right hand with the stylus on a second identical laptop tablet. Two identical Microsoft Surface Pro 4 laptop tablets with Type Cover and Surface-pen were used, while laptop data produced by the participants were stored in Microsoft OneNote for offline analyses.

Audrey L. H. van der Meer, PhD, MSc.
Frederikus Roelof (Ruud) van der Weel, PhD, MSc, BSc.

Audrey Van der Meer is a professor of Neuropsychology and Ruud Van der Weel is a Professor of Cognitive Psychology, from the Department of Psychology at the Norwegian University of Science and Technology (NTNU), Norway.

Originally from The Netherlands, the pair moved to Norway 20 years ago after marrying to work together at the NTNU. The couple met at the Free University of Amsterdam in The Netherlands while both studying for a Master of Science in Human Movement Sciences, and then moved to Scotland together to attend The University of Edinburgh to obtain their PhDs in Psychology.

Well-respected researchers, van der Meer and van der Weel's work has been praised and published in a number of international journals. Their research has also been featured in the popular scientific television program Schrödingers Katt (Norway) in 1998, 2001, 2010, and 2015.

At the Developmental Neuroscience Laboratory, the couple has organised the PhD course Human Psychophysiology, which is now officially part of the Norwegian Research School in Neuroscience.

Last year, van der Meer took part in Rector Bovim's delegation to The Netherlands to promote teaching and research collaboration between TU Delft and NTNU. In November 2014 and April 2015, she was also invited to present her views as a brain researcher and Professor of Psychology on early stimulation of young children aged 0-3 years to Norwegian politicians at the Government Buildings in Oslo.