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# The Importance of Cursive Handwriting over Typewriting for Learning: A High-Density EEG Study in 12-Year-Old Adolescents and Young Adults

Master's thesis in Psychology
Supervisor: Audrey van der Meer
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# The Importance of Cursive Handwriting over Typewriting for Learning: A High-Density EEG Study in 12-Year-Old Adolescents and Young Adults

By

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May 2019

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Thank you!

Trondheim, May 2019
Eva Ose Askvik

## Sammendrag

Å skrive for hånd, på tastatur eller tegne - hva er best for læring? Med den økende digitaliseringen i dagens samfunn er det viktig å undersøke langtidsimplikasjonene disse endringene kan føre med seg i en skolesituasjon. Vi undersøkte hjerneaktiviteten til 12-åringer og unge voksne mens de hadde på seg en EEG-hette bestående av 256 sammensydde elektroder. Mens hjerneaktiviteten deres ble registrert, skulle de enten taste, skrive for hånd eller tegne et presentert ord, varierende i vanskelighetsgrad. Videre TSE-analyser (endringer i nevronsvingninger) ble utført for å undersøke aktiveringsmønstre i de tre ulike betingelsene. Vi fant at når deltakerne skrev for hånd i løkkeskrift med en digital penn på et nettbrett, viste parietal- og sentralområdene i hjernen synkroniserte nevronsvingninger i theta-rytmen. Eksisterende litteratur antyder at en slik type aktivitet i disse hjerneområdene er viktig for hukommelse og tilegnelse av ny kunnskap, dermed en fordel for læring. Når deltakerne tegnet, fant vi lignende aktiveringsmønstre i parietalområdene, i tillegg til desynkroniserte nevronsvingninger i høyere alfa- og beta-rytmen. Dette tyder på at tegning og håndskrift aktiver både lignende og forskjellige mønstre i hjernen. Ved tasting fant vi derimot desynkroniserte nevronsvingninger i theta-, og i mindre grad i alfa-rytmen, i de samme hjerneområdene. I og med at denne aktiviteten var desynkronisert og forskjellig fra håndskrift og tegning, er dens forhold til læring noe uklart. Vi konkluderte med at nødvendigheten av sansemotorisk integrasjon gjennom de presise håndbevegelsene gjennom håndskrift og tegning, åpner for læring. Det er derfor viktig å opprettholde både håndskrifts- og tegneaktiviteter i et læringsmiljø for å optimalisere læring.

# Abstract

To write by hand, type, or draw – which strategy is the most efficient for optimal learning? As digital devices are increasingly replacing traditional writing by hand, it is crucial to examine the long-term implications of this practice that are still largely unknown. Electroencephalogram (EEG) was used in 12-year-old adolescents and young adults to study brain electrical activity as they were writing in cursive by hand, typewriting, or drawing 15 visually presented words that were varying in difficulty. Analyses of temporal spectral evolution (time-dependent amplitude changes) were performed on EEG data recorded with a 256-channel sensor array. We found that when writing by hand using a digital pen on a touchscreen, brain areas in the parietal and central regions showed event-related synchronized activity in the theta range. Existing literature suggests that such oscillatory neuronal activity in these brain areas is important for memory and encoding of new information and, therefore, provides the brain with optimal conditions for learning. When drawing, we found similar activation patterns in the parietal areas, in addition to event-related desynchronization in the alpha/beta range, suggesting both similar and different activation patterns when drawing and writing by hand. When typewriting on a keyboard, we found event-related desynchronized activity in the theta, and to a lesser extent, in the alpha range in the same areas. However, as this activity was desynchronized and different from when writing by hand and drawing, its relation to learning remains unclear. We concluded that because of the benefits of sensory-motor integration and the involvement of fine hand movements found when writing by hand and drawing, it is vital to maintain both activities in a learning environment to facilitate and optimize learning.

*Keywords:* high-density electroencephalography (EEG), time-spectral evolution TSE, event-related desynchronization ERD, event-related synchronization ERS, cortical oscillations, learning, development, typewriting, cursive writing, drawing, children

# Introduction

Digital devices are increasingly replacing traditional writing by hand (Kiefer et al., 2015; Longcamp, Boucard, Gilhodes, & Velay, 2006), and as both reading and writing are becoming more and more digitized at all levels of education, it is crucial to examine the long-term implications of this practice that are still largely unknown (Mangen & Balsvik, 2016; Patterson & Patterson, 2017). The marginalization of handwriting raises questions about the actual future functionality of the handwriting skill (James & Engelhardt, 2012) and the contributions of writing movements to the development of written language representations (Longcamp et al., 2006). Despite several studies supporting the benefits for learning when taking notes by hand compared to laptop note-taking (e.g., James & Engelhardt, 2012; Longcamp, Zerbato-Poudou, & Velay, 2005; Mueller & Oppenheimer, 2014; Smoker, Murphy, & Rockwell, 2009; van der Meer & van der Weel, 2017), it is still unclear how computer use impacts student productivity and learning (Patterson & Patterson, 2017). Due to contradictory results, it has been hard to achieve an explicit agreement, whether the technology serves to help or hinder student performance. Therefore, it is essential to further investigate the long-term implications for learning and *how* the processes of cursive writing, typewriting, and drawing are working in the brain within a developmental perspective.

Cursive writing is a complex and central cultural skill (Kersey & James, 2013; Kiefer et al., 2015), involving many brain systems and the integration of both motor and perceptual skills (Thibon et al., 2018; Vinci-Booher, James, & James, 2016). The skill of cursive writing is often used as a tool for learning (Arnold et al., 2017), considering the depths of processing that note-taking by hand provides, even in the absence of a review of the notes (Kiewra, 1985). Thus, cursive writing has been considered an essential precursor for further academic success (Fears & Lockman, 2018), and the skill is typically acquired during childhood in societies with a strong literacy tradition (Kiefer et al., 2015). Children must learn how to coordinate their hand movements accurately and produce the shape of each letter, and they may take several years to master this precise skill (van der Meer & van der Weel, 2017). The need to understand the underlying processes that make cursive writing effective as a learning activity is becoming increasingly important (Arnold et al., 2017; Vinci-Booher et al., 2016).

Today, most adults write using a keyboard and computer (Longcamp et al., 2006; Longcamp et al., 2005), and in some countries' programs for elementary school education, typewriting on digital devices has already replaced traditional handwriting (Kiefer et al., 2015). Therefore, the amount of time spent writing by hand has been reduced as learning activities are increasingly relying upon digital devices (Mueller & Oppenheimer, 2014; Vinci-Booher et al., 2016). These devices (e.g., tablets and mobile phones) may improve a student's ability to take notes, but they may also hinder learning in different ways (Stacy & Cain, 2015). Most educators acknowledge note-taking as an important factor of classroom learning (Stacy & Cain, 2015), and keyboard activity is now often recommended as a substitute for early handwriting as this type of activity is less demanding and frustrating for children (Cunningham & Stanovich, 1990). Typewriting is beneficial in terms of both speed and quantity (Brown, 1988), making it possible to make an excessive amount of notes during a lecture. In addition, the ability to store copies of notes, and carrying notebooks and curriculum around at all times, without heavy backpacks (Carter, Greenberg, & Walker, 2017), might be the reason why many students prefer to take notes with computers rather than by hand. Besides, Kay and Lauricella (2011) found that even though students themselves admit that laptops are a distraction, they believe the benefits outweigh the costs.

Proponents of computers in the classroom stress the benefits of children being able to produce large texts earlier and receiving immediate feedback on their texts and questions through the Internet (Hultin & Westman, 2013). On the other hand, critics of computers in the classroom have found computer use to have a negative impact on course grades (Patterson & Patterson, 2017), lower class performance (Fried, 2008), as well as being distracting in the way that students habitually multitask (Sana, Weston, & Cepeda, 2013). Compared to typewriting training, handwriting training has not only been found to improve better spelling accuracy (Cunningham & Stanovich, 1990) and better memory and recall (Longcamp et al., 2006; Mueller & Oppenheimer, 2014; Smoker et al., 2009), but also improved letter recognition (Longcamp, Boucard, Gilhodes, & Anton, 2008; Longcamp et al., 2005). These results suggest that the involvement of the intricate hand movements and shaping of each letter may be beneficial in several ways. Therefore, the next question might be if *any* motor activity facilitates learning, or if the keyboard and pen cause different underlying neurological processes within the brain. If so, changing the motor condition while children are learning may affect their subsequent performance (Longcamp et al., 2005).

From the sensorimotor point of view, cursive writing and typewriting are two distinct ways of writing and may as well involve distinct processes in the brain (Alonso, 2015; Longcamp et al., 2006; Longcamp et al., 2005). The process of cursive writing involves fine coordination of hand movements when producing the shape of each letter, whereas typewriting requires much less kinesthetic information (Kiefer et al., 2015; Longcamp et al., 2006; Smoker et al., 2009). Several fMRI-studies, in preliterate (James & Engelhardt, 2012) and preschool children (e.g., James, 2010; James, 2017; Vinci-Booher et al., 2016), as well as adults (Longcamp, Anton, Roth, & Velay, 2003; Menon & Desmond, 2001), have shown that areas related to writing processes are also activated when simply perceiving visual letters, suggesting that writing and reading are interrelated processes including a sensorimotor component (Longcamp et al., 2006; Longcamp et al., 2005).

Even though several researchers have pointed to certain task-specific brain areas, recent findings in modern neuroscience suggest that the brain is not that simple. Neural processes are highly dynamic (Lopes da Silva, 1991; Singer, 1993) and we still know very little about *how* the different brain systems are working together (Buzsáki, 2006). As recent findings of cognitive neuroscience have found processes in the brain to occur every millisecond, the EEG technique lends itself well to studying brain electrical activity as a function of cursive writing, typewriting, and drawing. Instead of investigating each brain area individually, we can study the brain in terms of the frequently occurring brain rhythms, also called oscillations. The EEG-technique allows us to investigate changes in the state of the underlying networks (Lopes da Silva, 1991), and can reveal the continuously changing task-specific spatial patterns of activations (Pfurtscheller, Stancak, & Neuper, 1996). Recently, studies of cortical oscillations have rapidly evolved and received considerable attention with modern EEG (Hoechstetter et al., 2004; Lopes da Silva, 1991). These studies have become a fundamental aspect of modern systems neuroscience, yet, there are still conflicting definitions regarding the different rhythms and their cognitive usefulness (Fröhlich, 2016).

In general, brain oscillations are interactions between the thalamus and cortex and can be viewed as generated by changes in one or more parameters that control oscillations in neuronal networks (Pfurtscheller & Lopes da Silva, 1999). The complex interactions and the following distinctive frequencies are, in short, reflecting different cognitive processes (Berens & Horner, 2017; Klimesch, Schimke, & Schwaiger, 1994), for example between cursive writing, typewriting, and drawing. At the neural level, cortical oscillations have been found to reflect periodically membrane voltages that interact by synaptic transmission, reflecting a pattern of depolarization and hyperpolarization that enables or disables effective translation of incoming synaptic input into postsynaptic action potential firing (Fröhlich, 2016). In other words, the frequencies of the following oscillations depend both on the individual neurons and the strength of the action potentials (Lopes da Silva, 1991; Singer, 1993). This temporal organization of neural firing is of high importance and is also thought to be critical for the formation of long-term memories in the hippocampus (Berens & Horner, 2017).

Frequency-specific changes in the ongoing EEG, that are not phase-locked to a specific event, can be observed in form of event-related synchronization (ERS) (an increase in spectral amplitude) or event-related desynchronization (ERD) (a decrease in spectral amplitude) (Pfurtscheller & Aranibar, 1977; Pfurtscheller & Lopes da Silva, 1999). These longer-lasting ongoing changes can be detected using spectral analyses (Klimesch, 1996), e.g., induced time-spectral evolution (TSE), to study differences in a given frequency band (Pfurtscheller, Neuper, & Mohl, 1994). Both ERD and ERS are highly frequency-specific and can be displayed in both the same or different locations on the scalp simultaneously (Lopes da Silva, 1991; Pfurtscheller & Lopes da Silva, 1999; Pfurtscheller et al., 1996).

In a recent EEG-study, van der Meer and van der Weel (2017) found that drawing by hand activates larger networks in the brain compared to typewriting, and concluded that the involvement of fine hand movements in note-taking, as opposed to simply pressing a key on a keyboard, may be more beneficial for learning. They found a desynchronized activity within the alpha band in the parietal and occipital areas of the brain, suggesting this activity to be beneficial for learning, especially as the activity was shown to occur in the rather deep structures of the brain (e.g., hippocampus, the limbic system). Both handwriting and drawing are complex tasks that require integration of various skills (van der Meer & van der Weel, 2017), and adults often use the same term to refer to young children's writings and drawings (Treiman & Yin, 2011). Both processes involve several visuomotor components and precise coordination (Planton, Longcamp, Péran, Démonet, & Jucla, 2017) to produce artificial marks that appear on a surface (Treiman & Yin, 2011). As drawing can be said to be just as complex as handwriting, this activity is not used daily as an intensive learning strategy in the form of written productions (Planton et al., 2017). Therefore, it would be interesting to investigate whether drawing and cursive writing engage similar or different activation patterns in the brain, and how they differ from typewriting on a keyboard based on the literature mentioned above.

As previous studies have found support for the benefits of note-taking by hand in terms of learning, the present study aimed to expand the findings by van der Meer and van der

Weel (2017), and further investigate the neurobiological differences in the adult and child brain related to cursive writing, typewriting, and drawing, using high-density EEG. It was hypothesized that handwriting and drawing would activate similar brain areas, in profound structures of the parietal lobe, to a greater extent than typewriting on a keyboard. Studying the adult brain state can provide valuable information (Vinci-Booher et al., 2016), but investigating the stages that lead to the adult-like neural signatures can help us better understand cognitive development and why the brain responds to certain stimuli the way it does as a result of experience (James, 2010). Therefore, the present study includes a group of 12-year-old children, in addition to adults, to investigate if the same activations are apparent as in the literate adult, and perhaps even more critical in terms of learning and initiation of essential neuronal structures in the brain. Hence, the present study aims to investigate the importance of teaching cursive writing in school and to further explore which strategies of cursive writing, typewriting, or drawing is more beneficial to facilitate and optimize learning.

# Methods

## Participants

Sixteen healthy school-aged children and sixteen healthy adults were recruited to participate in this study at NU-lab at NTNU (Norwegian University of Science and Technology) (see Appendix A for information sheet in Norwegian). The study followed a cross-sectional design to study differences in oscillatory brain activity in tasks of cursive writing, typewriting, and drawing among children and adults. The school-aged children were recruited from 7th graders at the Waldorf school in Trondheim. Interested parents contacted the lab for further information about their child's participation. The adults were recruited through different lectures at NTNU Dragvoll, or they were contacted through friends. All participants were right-handed, as determined by the Edinburgh Handedness Inventory (Oldfield, 1971) (see Appendix B for a Norwegian version of the Edinburgh Handedness Inventory). Only right-handed participants with a handedness quotient of $\geq + 0.6$ took part in this study, ranging from lowest to highest, 0.65 to 0.93 in adults and .60 to 1.00 in school-age children, respectively. Four of the children were removed from further analysis due to inadequate data or other information that could affect the data analyses (e.g., dyslexia, ADHD, or prematurity). In addition, four of the adults were removed due to inadequate data and to maintain equal sized groups. Because of this, the resulting total sample included twelve school-aged children and twelve adults.

For the school-aged children (four boys and eight girls), the mean age was 11.83 years (*SD* = 0.39). Parents gave their informed consent concerning their children, and the child could withdraw from the experiment at any time without any consequences. For the adults (six men and six women), the mean age was 23.58 years (*SD* = 2.02). The adults also gave their informed consent and could withdraw at any time. The adults were rewarded with a 150 NOK cinema ticket, whereas the school-aged children were rewarded with snacks in the lab and a picture of themselves with the EEG-net on. The study did not need approval from the Norwegian Regional Ethics Committee.

## Experimental Stimuli and Paradigm

Psychological software tool, E-prime 2.0, was used to generate 15 different Pictionary words on a separate Microsoft Surface Studio. The participants used a digital pen to write in cursive by hand and draw directly on the touch screen, and a keyboard to typewrite the presented words. The screen measured 25.1''x 17.3''x 0.5'' and had a screen resolution of 4500 x 3000 (192 PPI) pixels.

The experiment included a total of 45 trials, where each word was presented in three different conditions, represented in a semi-randomized order. The 15 words varied in difficulty, from concrete words, such as "shoe", to more abstract words, such as "birthday". For each trial, participants were instructed to either (a) *write in cursive* the presented word with a digital pen directly on the screen, (b) *type* the presented word using the right index finger on the keyboard, or (c) *draw* the presented word by freehand with a digital pen directly on the screen. Before each trial, an instruction appeared 1-2 s before one of the 15 target words appeared, and the participants were given 25 s to either handwrite, type, or draw the word. EEG data were recorded only during the first 5 s of each trial. The participants could draw and write wherever they preferred directly on the screen. The words that were typed were the only words that did not appear on the screen while the participant was typewriting. A small sound indicated that the current trial was over and a new one was about to start. The drawings and writings produced by the participants were stored for offline analyses (see Figure 1).

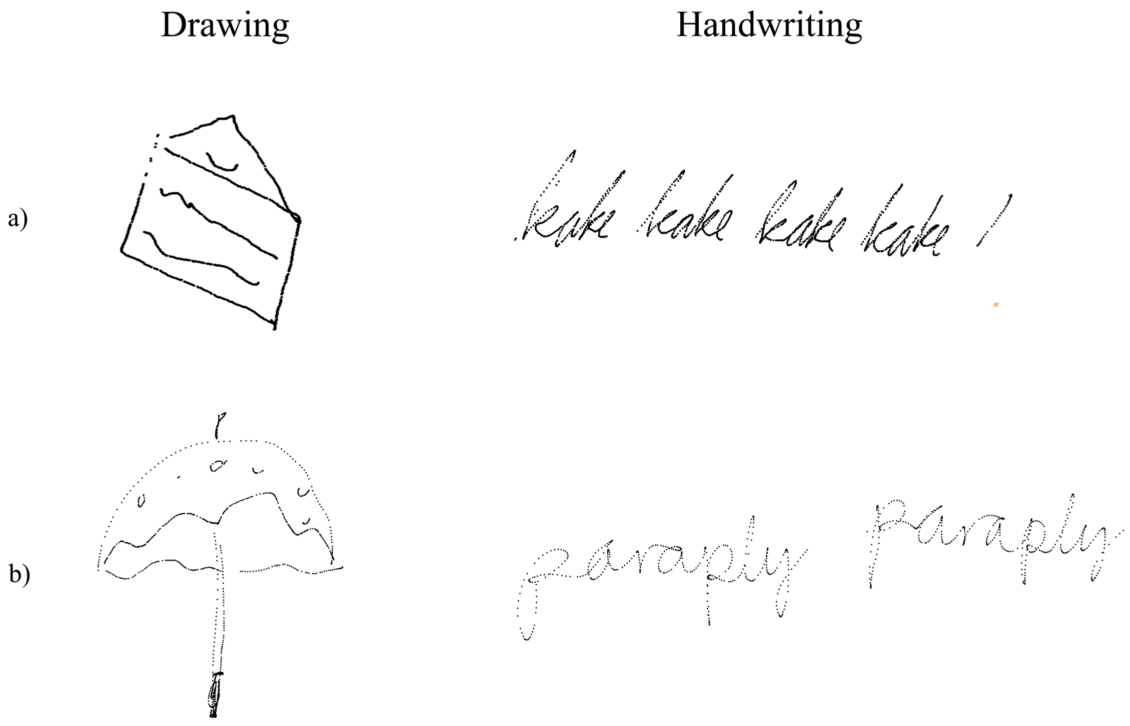

*Figure 1.* Example of writings and drawings in (a) a 12-year-old boy and (b) a 23-year-old female student.

## EEG Data Acquisition

An EEG Geodesic Sensor Net (GSN) (Tucker, 1993; Tucker, Liotti, Potts, Russell, & Posner, 1994) with 256 evenly distributed sensors was used to record EEG activity from the participant's scalp. The signals were amplified using a high-input EGI amplifier, at maximum impedance at 50 kΩ recommended for optimal signal-to-noise ratio (Ferree, Luu, Russell, & Tucker, 2001; Picton et al., 2000). The amplified signals were recorded by Net Station software with a sample rate of 500 Hz. All data were stored for further off-line analyses.

## Procedure

Participants usually arrived several minutes prior to the experiment. On arrival, a consent form with all necessary information was given to the participants to sign. For the children, both the parent and child signed the consent form (see Appendix C and D for Norwegian versions of the consent forms for the adults and children, respectively). The participant's head was measured to find the correct size for the net. While the participant completed the Edinburgh Handedness Inventory (Oldfield, 1971), the net was soaked in a saline electrolyte for 15 minutes to optimize electrical conductivity. After being partially dried from the soaking, the net was mounted on the participant's head. Next, the participant was moved to the experimental room where further information regarding the experiment was given. The experimental room was separated from the control room, where two assistants operated the computers necessary for data acquisition. The participant was sitting comfortably in an adjustable chair in front of a table with two levels, to minimize unnecessary movement in between trials that could cause artifacts in the data. A pillow was used to avoid tension in the back, and the table with the screen (on the second level) was placed as close as possible to the participant. A keyboard was further placed (on the nearest level) in a preferred position for the participant, and a digital pen was used for writing and drawing on the screen. The participants were asked to support their elbow to minimize hand movements in the trials using the pen. In addition, they were asked to sit as still as possible, while at the same time trying to perform the tasks as

*Figure 2*. Experimental set-up with a participant wearing the Geodesic Sensor Net. Participant is sitting comfortably in a chair, with a pillow in her back and her elbow resting on the nearest table.

naturally as possible. Figure 2 shows the experimental set-up for a typical participant. The EEG-net was connected to the amplifier and the impedance of the electrodes was checked. Electrode connectivity could be improved by either adjusting their position or by adding additional saline electrolyte for better contact.

A pre-test was completed before the actual experiment where one of the assistants was present in the room. During this test, the participants could ask questions if needed, and necessary adjustments could be made. The pre-test included one example of each experimental condition, using a word not included in the actual experiment. The experiment started immediately after the pre-test was finished, the impedance was approved, and the participant was ready.

Two experiments were conducted at the same time, with a total of six different conditions, resulting in a total of 90 trials. However, the focus of this paper is on the three experimental conditions handwriting, typewriting, and drawing. Data acquisition was carried out in two blocks (45 trials in each) and lasted for about 45 minutes. Between the two different blocks, the participants were given a pause where they could drink water and have a break from the screen. A pause was also initiated if the participant was moving a lot or appeared nervous, to remind the participant to relax and sit as still as possible. Further, the participants were told to knock on the window, separating the experimental room and control room, if they needed additional breaks or had any questions during the experiment.

## Data Pre-Analyses

Brain Electrical Source Analysis (BESA) research software version 6.1 was used to analyze the EEG data. Recordings were segmented using the Net Station software and then exported as raw files with the appropriate auxiliary files attached, prior to the analyses in BESA. Average epoch was set to -250 ms to 4500 ms with a baseline definition of -250 ms to 0 ms. Low cut-off filter was set to 1.6 Hz to remove slow drift in the data, while the high cut-off filter was set to 75 Hz. The notch filter was set to 50 Hz to avoid line interference in the data.

Artifact contaminated channels, caused by head or body movements, were either removed or interpolated using spherical spline interpolation (Perrin, Pernier, Bertrand, & Echallier, 1989; Picton et al., 2000). A maximum limit of 10% of the channels could be defined as bad, resulting in participants with more than 10% channels defined as bad being excluded from further analyses. When scanning for artifacts, threshold values for gradient, low signal, and maximum amplitude were set to 75 µV, 0.1 µV and 200 µV, respectively.

Manual artifact correction was applied to separate important brain activity from artifacts using manual and semi-automatic artifact correction with fitting spatial filters (Berg & Scherg, 1994; Fujioka, Mourad, He, & Trainor, 2011; Ille, Berg, & Scherg, 2002). When it was not possible to apply manual artifact correction, an automatic artifact correction (with values 150 µV for horizontal and 250 µV for vertical electrooculogram amplitude thresholds) was applied to explain artifact topographies by principal component analysis (PCA) (Ille et al., 2002).

For the school-aged children, the mean numbers of accepted trials were 11.17 (*SD* = 1.90) for handwriting, 9.50 (*SD* = 2.32) for typewriting, and 12.08 (*SD* = 2.02) for drawing, respectively. For the adults, the mean numbers of accepted trials were 14.33 (*SD* = 0.98) for handwriting, 13.42 (*SD* = 1.24) for typewriting, and 14.08 (*SD* = 1.56) for drawing, respectively. After all the data were sufficiently artifact-free, time-frequency analysis in brain space was performed.

### Time-Frequency Analyses in Brain Space

Time-frequency analysis in brain space was conducted for analysis of oscillatory activity, using multiple source dipoles that modeled the main brain regions of interest (see Figure 2). As the EEG-technique measures voltage changes at the scalp around dipoles, the orientations of these dipoles are essential as they provide specific distribution of an EEG-activity (Fröhlich, 2016; Luck, 2005). Measuring oscillatory activity directly on scalp surface electrodes may not be ideal, due to mixed brain source contributions and wide distribution of focal brain activity on the scalp surface caused by the nature of dipole fields and the smearing effect of volume conduction in EEG. Therefore, optimal separation of brain activity was achieved using source montages derived from a multiple source model where waveforms separated different brain activities (Scherg & Berg, 1991). The regional sources of interest included the frontal, central, temporal, parietal, and occipital areas (see Figure 3), as in compliance with van der Meer and van der Weel (2017). A 4-shell ellipsoidal head model was used to analyze the sources of interest (Berg & Scherg, 1994; Hoechstetter et al., 2004) of each participant after loading the artifact-corrected coordinate files.

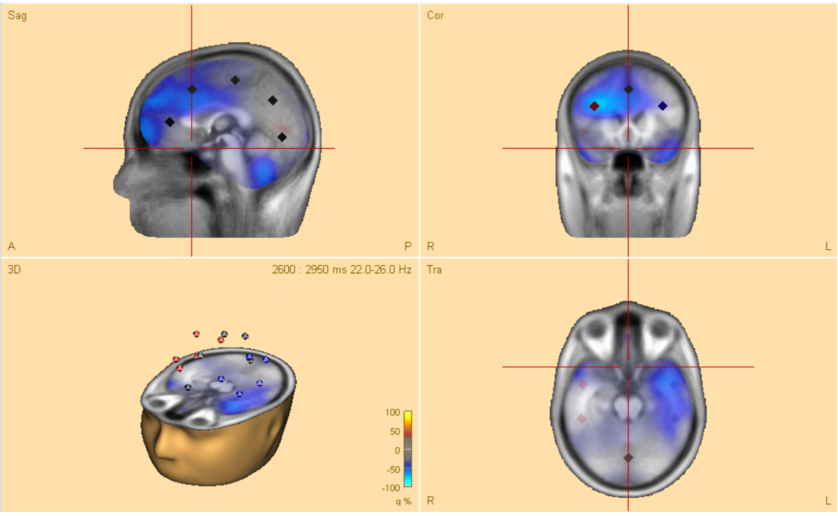

*Figure 3.* Head model of a typical 12-year-old boy. The model shows four dipoles (with location and direction of electrical current) in regional sources of interest, over frontal, central, temporal parietal, as well as occipital areas.

Average evoked response signals were subtracted in BESA to focus only on induced brain activity in the TSE (Pfurtscheller et al., 1994). Comparisons between the three conditions handwriting, typewriting, and drawing were computed for each participant with time-frequency displays (changes in amplitude over time). TSE displays were limited between frequency cut-offs of 4-60 Hz, while frequency and time sampling were sat at 1 Hz and 50 ms.

## Statistical Analyses

Probability of significance in amplitude values and frequency ranges between each of the three conditions was tested with BESA Statistics 2.0. Using this program, average TSE statistics for each participant could be computed to use these significant time-frequency ranges as guides in finding maximum oscillatory activity in the individual TSEs. To address the multiple comparisons problem, a combination of permutation tests and data clustering was employed in the statistical test. Data clusters that showed a significant effect between conditions were assigned initial cluster values. Using both between-groups and within-group ANOVA’s, these initial cluster values were passed through permutation and assigned new clusters so that the significance of the initial clusters could be determined. A Bonferroni correction was used to adjust for multiple comparisons (Simes, 1986). Cluster alpha (the significance level for building clusters in time and/or frequency) was set at 0.01, and the number of permutations was set at 10.000. Low- and high cut-offs for frequency were kept at 4 Hz and 60 Hz, and epochs were set from -250 to 4500 ms. Post-hoc tests were run to test for statistical differences between the three conditions and two age groups.

# Results

## Individual Time-Frequency Responses

Figure 4 and 5 display the results of individual TSE (time spectral evolution) maps of brain regions of interest for the three experimental conditions handwriting, typewriting, and drawing, for a typical child and adult participant. Brain regions of interest included frontal, temporal, parietal, central as well as occipital areas, in frequencies from theta (4 Hz) and up to gamma (60 Hz) range. The signal magnitude (amplitude %) reflects estimated neural activity in the various brain regions compared to baseline (-250 to 0 ms) activity. Increased spectral amplitude [induced synchronized activity, event-related synchronization, (ERS)] is shown as red-colored contours and decreased spectral amplitude [induced desynchronized activity, event-related desynchronization (ERD)], is shown as blue-colored contours.

In the parietal and central areas, event-related synchronization (ERS) was more prominent in lower frequencies (theta 4-8 Hz) for handwriting and drawing, as opposed to in higher frequencies (beta 12-20 Hz, and gamma > 20 Hz) for typewriting. As for event-related desynchronization (ERD), this activity was more prominent in higher frequencies (beta 12-20 Hz, and gamma > 20 Hz) for handwriting and drawing and in lower frequencies (theta 4-8 Hz) for typewriting. These patterns were consistent in both adults (see Figure 4) and children (see Figure 5).

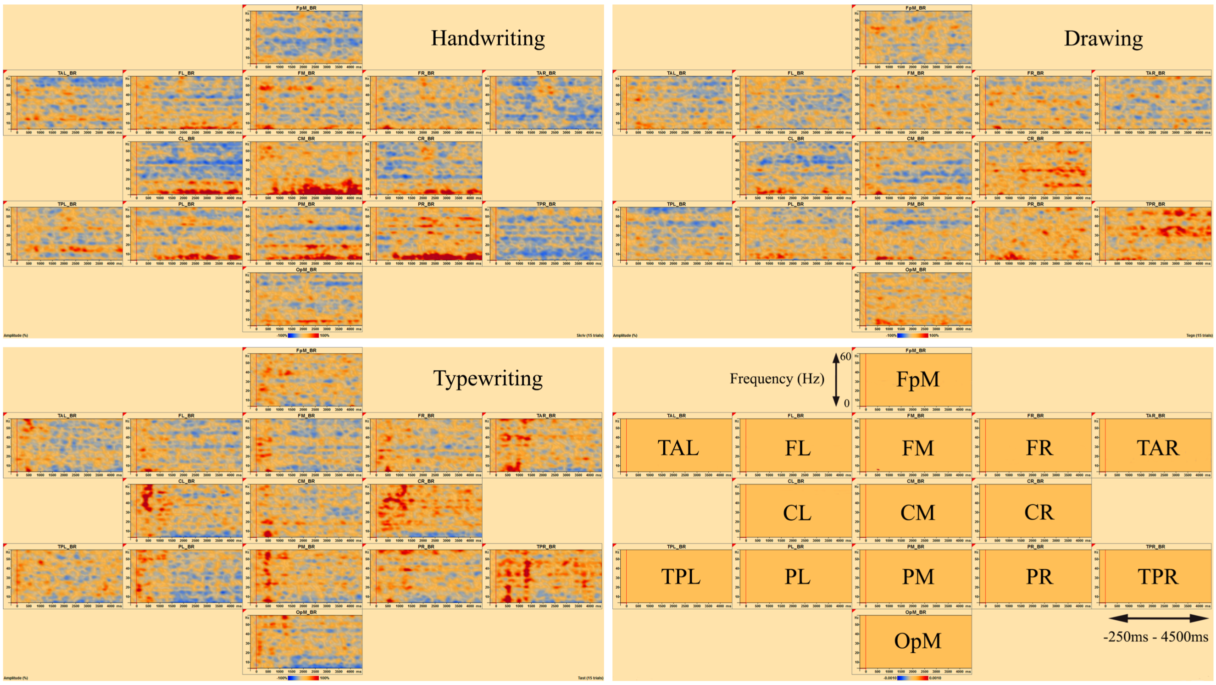

*Figure 4.* Individual time-frequency displays of a typical (male) adult. Event-related synchronization (ERS) is shown as red-colored contours, more prominent in lower frequencies (theta 4-8 Hz) for handwriting and drawing and higher frequencies (beta 12-20 Hz and gamma > 20) for typing. Event-related desynchronization (ERD) is shown as blue-colored contours, more prominent in higher frequencies (beta 12-20 Hz and gamma > 20) for handwriting and drawing and lower frequencies (theta 4-8 Hz) for typing. Brain areas included the following frontal, temporal, central, parietal and occipital areas: FpM, fronto-polar midline; FL, frontal left; FM, frontal midline; FR, frontal right; TAL, temporal anterior left; TAR, temporal anterior right; TPL, temporal posterior left; TPR, temporal posterior right; CL, central left; CM, central midline; CR, central right; PL, parietal left; PM, parietal midline; PR, parietal right; OpM, occipito-polar midline. The y-axes display signal magnitude (amplitude %) reflecting estimated neural activity in the various brain regions compared to baseline (-250 to 0 ms) activity. The x-axes display the time interval including the baseline activity (-250 to 0 ms) and 4500 ms of recordings of the trial.

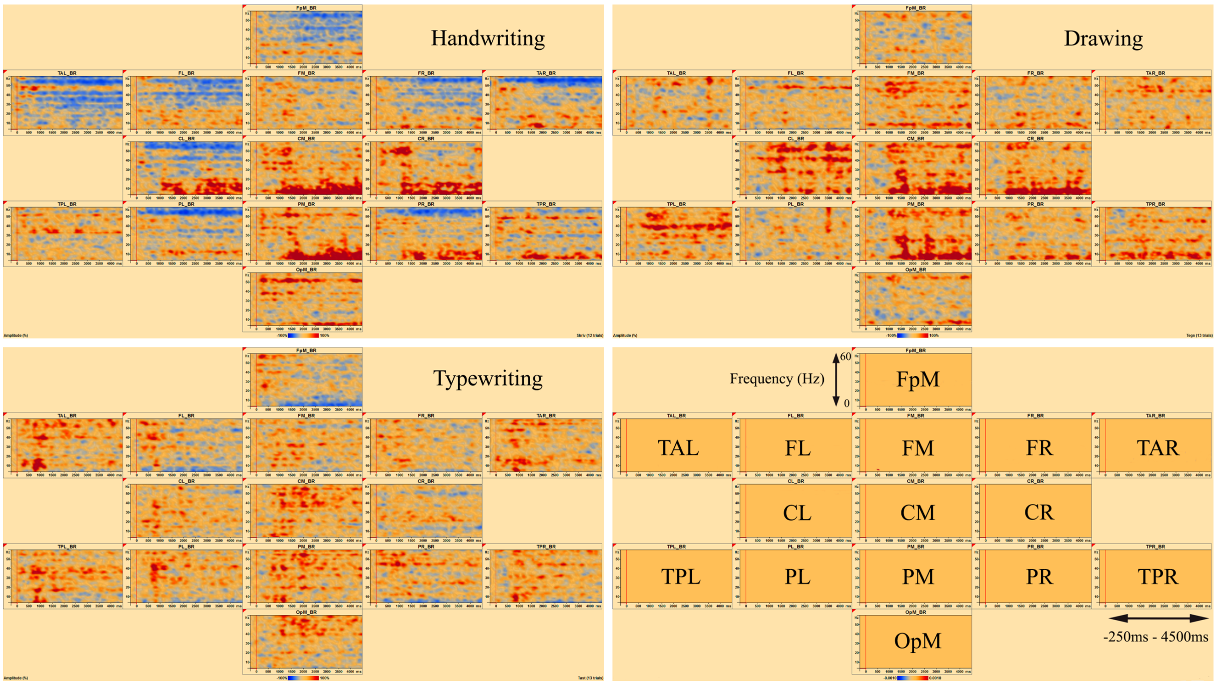

*Figure 5.* Individual time-frequency displays of a typical (female) 12-year-old, in frontal, temporal, central, parietal and occipital areas. Event-related synchronization (ERS) is shown as red-colored contours and event-related desynchronization (ERD) is shown as blue-colored contours, showing the same activation patterns as the adult above. The y-axes display signal magnitude (amplitude %) reflecting estimated neural activity in the various brain regions compared to baseline (-250 to 0 ms) activity. The x-axes display the time interval including the baseline activity (-250 to 0 ms) and 4500 ms of recordings of the trial.

### Main Effects and Post-Hoc Analyses

Statistical analyses were run to test for statistical differences between the conditions and groups. Table 1 and 2 display the detailed main effects (within-group ANOVA) of the permutation results (of clusters where the null hypothesis is rejected, i.e., data are not interchangeable) of the adults and children, respectively. These results revealed ten significant clusters for both groups.

Table 1

*Permutation test of adult results for ten significant clusters in decreasing order*

| Cluster ID | *p*-value | Cluster value | Mean for type | Mean for draw | Mean for handwrite | Start time | End time | Start frequency | End frequency |
|---|---|---|---|---|---|---|---|---|---|
| TPL | 0.0009 | 1377.66 | -0.32 | -0.07 | -0.08 | 2100 | 4500 | 4 | 8 |
| PR | 0.0026 | 1167.58 | -0.23 | -0.11 | 0.21 | 2350 | 4050 | 4 | 11 |
| PM | 0.0034 | 1055.28 | -0.12 | 0.06 | 0.34 | 2400 | 4000 | 4 | 9 |
| PR | 0.0068 | 832.65 | -0.26 | -0.05 | 0.14 | 1200 | 2500 | 4 | 8 |
| CL | 0.0084 | 769.44 | -0.18 | -0.13 | 0.22 | 3700 | 4500 | 4 | 15 |
| PL | 0.0116 | 707.28 | -0.22 | -0.09 | 0.25 | 2750 | 3550 | 4 | 12 |
| TPR | 0.0141 | 663.75 | -0.30 | -0.03 | -0.03 | 2800 | 3650 | 4 | 11 |
| PL | 0.0141 | 660.31 | -0.22 | -0.07 | 0.25 | 3650 | 4500 | 4 | 10 |
| PL | 0.0264 | 559.76 | -0.20 | -0.06 | 0.19 | 1200 | 1950 | 4 | 12 |
| CM | 0.0345 | 508.77 | -0.03 | -0.04 | 0.34 | 3800 | 4400 | 6 | 14 |

*Note*. TPL, temporal parietal left; PR, parietal right; PM, parietal midline; CL, central left; PL, parietal left; TPR, temporal parietal right; CM, central medial.

Table 2

*Permutation test of child results for ten significant clusters in decreasing order*

| Cluster ID | *p*-value | Cluster value | Mean for type | Mean for draw | Mean for handwrite | Start time | End time | Start frequency | End frequency |
|---|---|---|---|---|---|---|---|---|---|
| PR | 0.0004 | 3303.8 | -0.33 | 0.17 | 0.00 | 1850 | 4500 | 4 | 16 |
| TPR | 0.0015 | 2208.41 | -0.27 | 0.34 | 0.02 | 1100 | 3000 | 4 | 14 |
| OpM | 0.0064 | 1402.64 | -0.37 | 0.14 | 0.06 | 3350 | 4500 | 4 | 12 |
| TPR | 0.0080 | 1278.56 | -0.41 | 0.05 | -0.11 | 3100 | 4400 | 4 | 9 |
| PL | 0.0138 | 1035.68 | -0.25 | 0.14 | -0.09 | 2050 | 3050 | 4 | 15 |
| TAR | 0.0152 | 991.50 | -0.30 | 0.04 | -0.01 | 3250 | 4500 | 4 | 11 |
| CR | 0.0193 | 900.39 | 0.38 | -0.13 | -0.04 | 600 | 1050 | 26 | 43 |
| OpM | 0.0207 | 881.26 | -0.26 | 0.34 | -0.02 | 1850 | 2500 | 4 | 15 |
| PL | 0.0303 | 761.26 | -0.35 | 0.01 | -0.08 | 3750 | 4500 | 4 | 13 |
| CL | 0.0450 | 646.94 | -0.26 | 0.14 | 0.03 | 2300 | 3600 | 5 | 10 |

*Note*. PR, parietal right; TPR, temporal parietal right; OpM, occipito-polar midline; PL, parietal left; TAR, temporal anterior right; CR, central right; CL, central left.

The post-hoc tests revealed significant differences in oscillatory activity in the alpha (8-12 Hz) and theta (4-8 Hz) band between handwriting, typewriting, and drawing among the adults, and between typewriting and drawing among the children. As the differences between typewriting and drawing, in both children and adults, were similar to the differences between typewriting and handwriting in adults, only the statistical differences between typewriting and handwriting, and handwriting and drawing in the adults are reported here. Further investigations of the parietal and central brain areas in both children and adults were conducted to study the importance of the different learning strategies within a developmental perspective.

Figure 6 and 7 display the post-hoc results of the permutation tests in the adults between handwriting and typewriting, and between handwriting and drawing, respectively. When handwriting was compared to typewriting, the permutation results showed three significant positive clusters (in black), in the parietal right (PR), parietal midline (PM), and parietal left (PL) areas (see Figure 6). Further, when handwriting was compared to drawing, the results showed one significant positive cluster (in black), in the central medial (CM) area (see Figure 7). These positive clusters suggest separate processes (due to a difference in band power) between handwriting and typewriting in the parietal areas, as well as separate processes between handwriting and drawing in the central midline area.

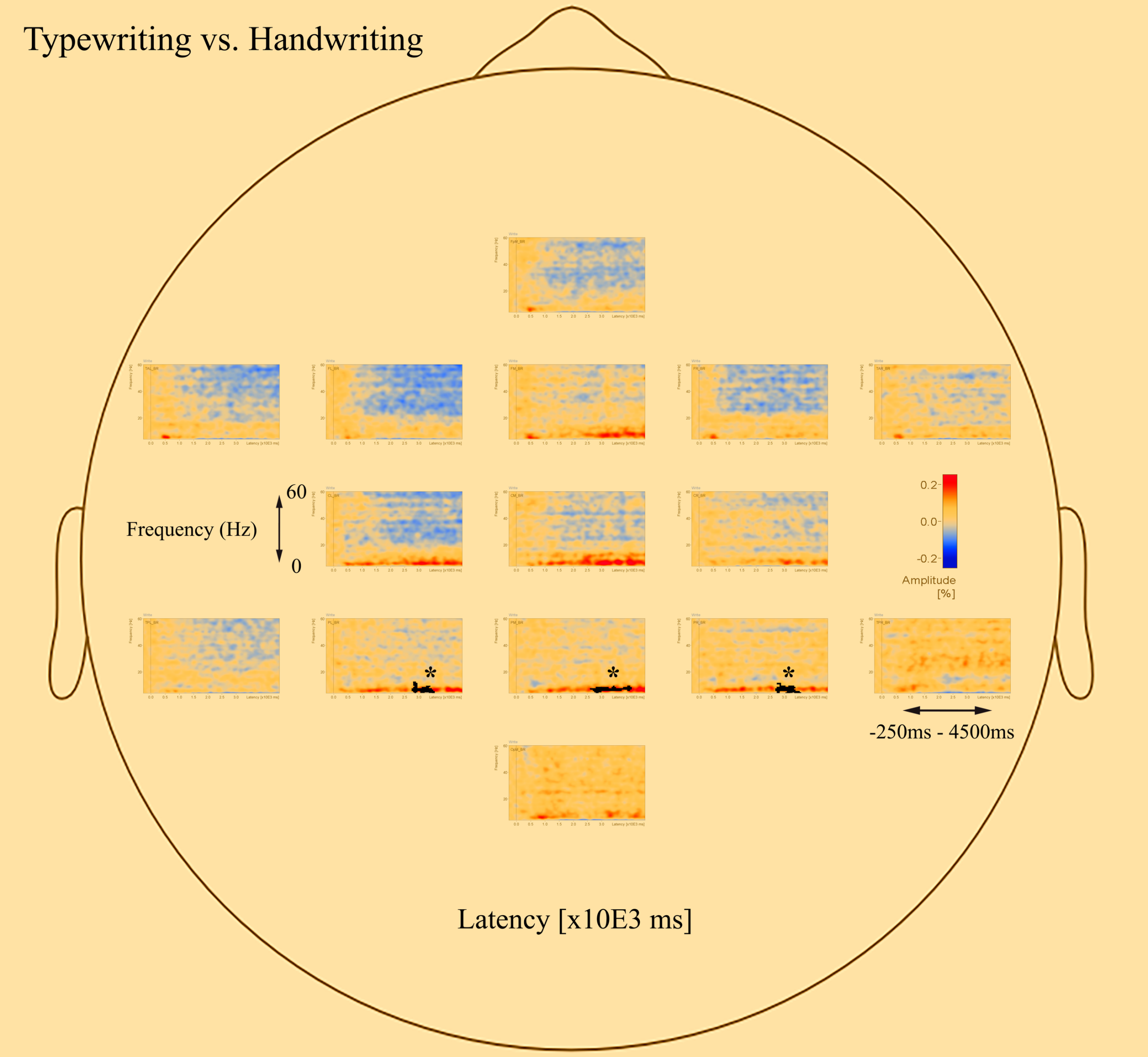

*Figure 6.* Head model (nose up) with average significant (* $p < 0.05$) data clusters in the various sources of interest when handwriting (displayed here) is compared to typewriting in all adults. Three significant clusters (marked in black) were found in the parietal right (PM), parietal midline (PM), and parietal left (PM). For handwriting, an event-related synchronized activity in the theta (4-8 Hz) range is apparent in parietal, central, occipital, as well as in frontal areas. Event-related desynchronization is apparent in the gamma (> 20 Hz) range in the central and frontal areas.

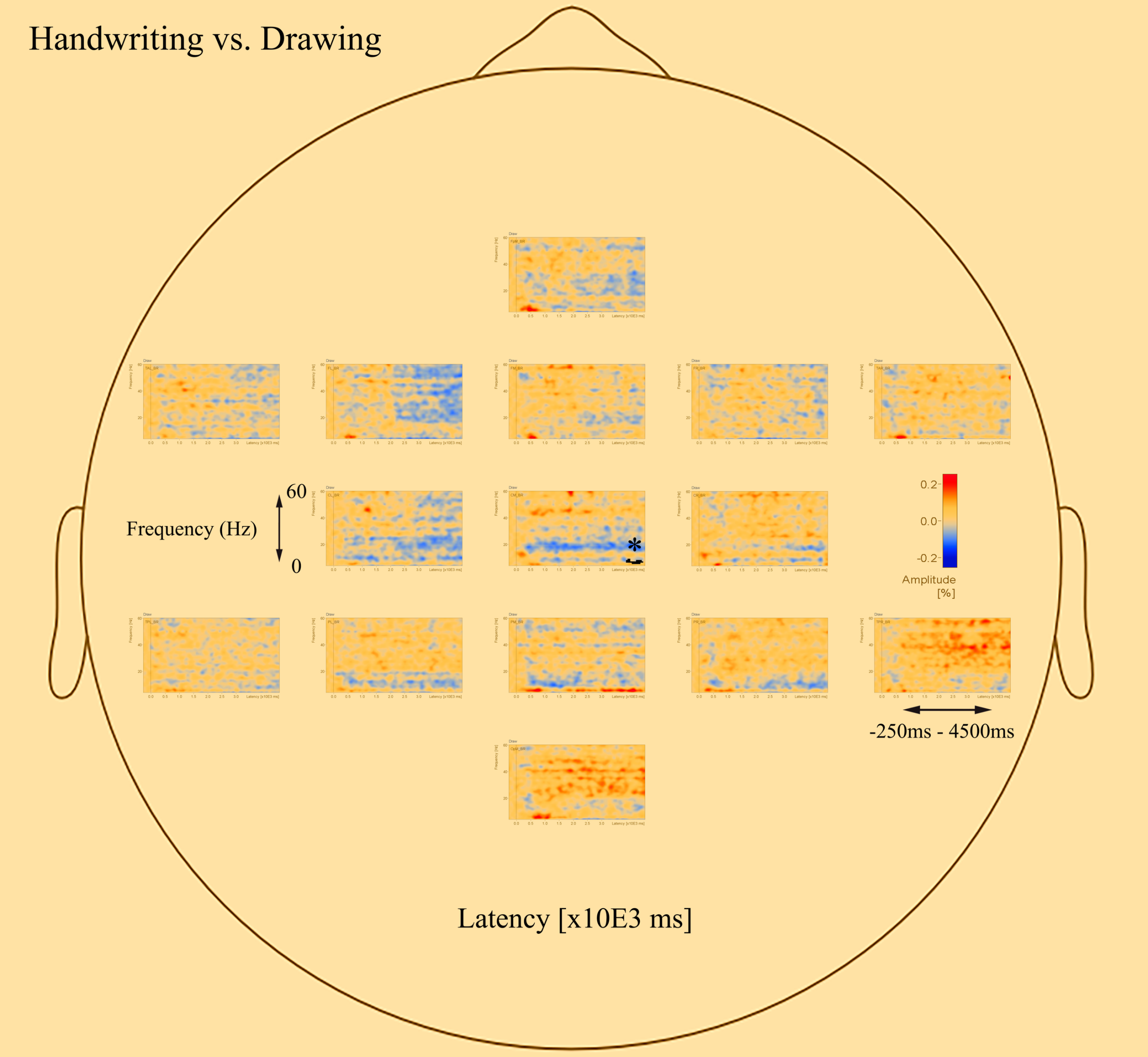

*Figure 7.* Head model (nose up) with average significant (* $p < 0.05$) data clusters in the various sources of interest when drawing (displayed here) is compared to handwriting in all adults. One significant cluster (marked in black) was found in the central midline (CM). For drawing, areas in the parietal and central regions are dominated by a desynchronized activity in the alpha (8-12 Hz) and beta (12-20 Hz) range. Additionally, event-related synchronization is apparent in the theta (4-8 Hz) range in the parietal midline (PM).

The significant clusters of differences in band power were found mainly in the parietal and central regions. The parietal areas of the brain have been associated with cognitive processing of language and mechanisms for attention (e.g., Benedek, Schickel, Jauk, Fink, & Neubauer, 2014; Brownsett & Wise, 2010; Pfurtscheller et al., 1994), and the central areas are influenced by the somatosensory cortex (e.g.,Velasques et al., 2007). Therefore, these areas were chosen to further focus on the underlying brain electrical activity as a function of handwriting, typewriting, and drawing. Additionally, the potential deep structures of the brain, that may have their beneficial effects on learning (van der Meer & van der Weel, 2017), may be found in these areas.

Figure 8 displays the average of all participants in the handwriting, typewriting, and drawing conditions in the adults (see Figure 8a) and children (see Figure 8b) in the central and parietal brain regions of interest: the parietal midline (PM), the parietal right (PR), the parietal left (PL), and the central midline (CM). For the adults, handwriting appeared to be dominated by an event-related synchronization (ERS) in the theta (4-8 Hz) range, in addition to an event-related desynchronization (ERD) activity in the gamma (> 20) range. The theta activity appeared around 1000 ms and lasted throughout the trial. Contrary to handwriting, typewriting appeared to be dominated by an event-related desynchronized (ERD) (blue areas) activity in the theta (4-8 Hz) range and, to a lesser extent, in the alpha (8-12 Hz) range. This activity appeared around 1500 ms and lasted throughout the trial. For drawing, synchronized theta (4-8 Hz) activity was apparent in the parietal midline (PM) and parietal right (PR), in addition to desynchronized alpha (8-12 Hz) and beta (12-20 Hz) range activity from around 500 ms and throughout the trial (see Figure 8a). For the children, the same tendencies could be observed, but they were far less evident compared to the adults. The reason for this could be due to more artifact-contaminated data in the children, resulting in fewer trials. Nevertheless, for the children, desynchronized and synchronized theta (4-8 Hz) range activity was also apparent in typewriting and to a lesser extent in handwriting, respectively. The synchronized theta (4-8 Hz) range activity was also apparent, yet to a minimal degree, in the parietal midline (PM) in drawing. Additionally, a desynchronized activity appeared to be dominated in the gamma (> 20 Hz) range in handwriting (see Figure 8b).

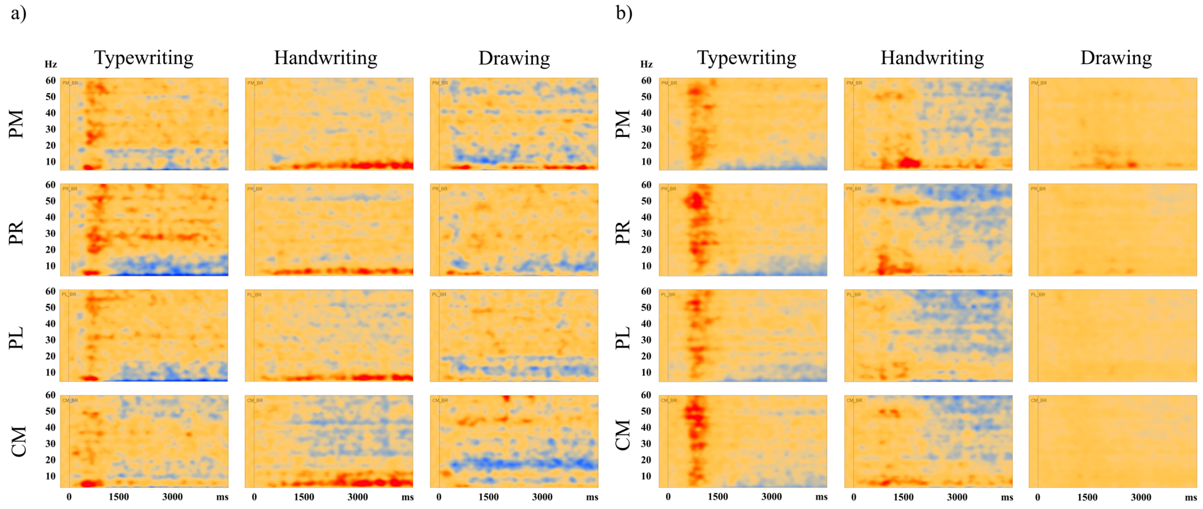

*Figure 8*. Average results of all participants for typewriting, handwriting, and drawing in the (a) adults and (b) children, in the parietal and central regions: PM, parietal midline; PR, parietal right; PL, parietal left; CM, central midline. For the adults, these areas showed event-related synchronization (ERS) in the theta (4-8 Hz) range for handwriting and event-related desynchronization (ERD) activity in the theta (4-8 Hz) and, to a lesser extent, in the alpha (8-12 Hz) range for typewriting. For drawing event-related synchronization (ERS) was apparent in the theta (4-8) range in parietal midline as with handwriting, in addition, an event-related desynchronization (ERD) activity was apparent in the alpha (8-12 Hz) and beta (12-20 Hz) range. These patterns were also apparent, though to a much lesser extent, in the children.

# Discussion

The aim of the current study was to further investigate brain electrical activity as a function of handwriting, typewriting, and drawing using high-density EEG in 12-year-old adolescents and adults. 15 different words, varying in task difficulty, were visually presented on a screen and the participants used a digital pen to write and draw directly on the touch screen, and a keyboard to type the presented words. TSE analyses were performed to explore underlying differences in brain oscillatory activity in the participants when they were using a keyboard versus a pen. In addition, the present study aimed to explore if drawing and cursive writing are activating similar or different processes. Regional sources of interest included frontal, temporal, parietal, central as well as occipital areas, in frequencies from theta (4 Hz) and up to gamma (60 Hz) range. To focus on the potential deep structures of the brain, that may have their beneficial effects on learning (van der Meer & van der Weel, 2017), the parietal and central areas were further investigated. These areas have additionally been associated with cognitive processes in language (e.g., Benedek et al., 2014; Brownsett & Wise, 2010; Pfurtscheller et al., 1994) and appear to be influenced by sensorimotor cortex (e.g., Velasques et al., 2007).

## TSE – Individual Analyses

The results reported above revealed differences in oscillatory activity between handwriting, typewriting, and drawing for both children and adults, though not all of them revealed significant clusters concerning the children. However, by visually reviewing individual TSE analyses of a typical participant in both groups, correspondingly, these revealed differences in band power (increase or decrease in spectral amplitude) between handwriting, typewriting, and drawing. Thus, handwriting, typewriting, and drawing seem to be different sensorimotor processes within the brain. However, it seems to be more similarities between handwriting and drawing, compared to typewriting, thereby supporting the study by van der Meer and van der Weel (2017).

## Synchronized Theta Activity in Parietal and Central Areas in Handwriting

Event-related synchronization within the theta (4-8 Hz) band has been found to correlate with working memory performance and the ability to encode new information (Clouter, Shapiro, & Hanslmayr, 2017; Klimesch, 1999; Klimesch et al., 2001; Klimesch et al., 1996; Klimesch et al., 1994; Raghavachari et al., 2001). Therefore, our findings seem to support the potential benefits of handwriting activity for learning. Klimesch et al. (1994) have also proposed that hippocampal activity is reflected within the theta band and shown as synchronized theta band power. However, this activity can be difficult to pick up with EEG, yet it is likely that the present activity stems from the rather deep structures of the brain (e.g., hippocampus and the limbic system) and adds further support for optimizing learning.

Moreover, Bland and Oddie (2001) have found support for synchronized theta activity in mechanisms underlying sensorimotor integration. Although the present study does not replicate the desynchronized activity in the alpha band found by van der Meer and van der Weel (2017), it, nevertheless, supports the findings because both ERS and ERD are highly frequency specific, i.e., the alpha and theta band respond in different and opposite ways (Pfurtscheller & Lopes da Silva, 1999; Pfurtscheller et al., 1996). In terms of cognitive effort, where the alpha band desynchronizes, the theta band synchronizes. Therefore, theta synchronization may indicate that different neural generators are involved, as with alpha desynchronization (Klimesch, 1999; Klimesch et al., 1994). Thus, our findings support the study by van der Meer and van der Weel (2017), but in a different frequency band. However, whereas alpha desynchronization is highly task-specific and correlates with (semantic) long-term memory performance, theta synchronization correlates with working memory performance and the ability to encode new information (Clouter et al., 2017; Klimesch, 1999; Klimesch et al., 2001; Klimesch et al., 1996; Klimesch et al., 1994).

In addition, lower frequencies are ideal for enabling communication over longer distances in the brain, and several studies have found support for lower frequencies to “gate” the occurrence of faster oscillations. Thus, the theta (4-8 Hz) oscillation in humans often gates the gamma (> 20 Hz) oscillation (Canolty et al., 2006). For handwriting, especially in the individual TSE-analyses, desynchronized gamma (> 20 Hz) activity was apparent together with synchronized theta (4-8 Hz) activity (see Figure 4). In general, gamma oscillations appears to be underlying mechanisms of neural coding (Singer, 1993), and this theta-to-gamma cross-frequency coupling seems to be related to studies finding gamma networks to desynchronize and theta networks to synchronize during encoding, retrieval (Solomon et al., 2017), as well as during episodic memory formation (Burke et al., 2013). Solomon et al. (2017) have also suggested low-frequency oscillations to be essential for interregional communication in the human brain. However, other studies (e.g., Osipova et al., 2006), have found synchronized activity in both theta and gamma bands, thereby indicating that further research of this coupling is needed. Also, because of the broad definition of the gamma frequency (20-100 Hz), we only observed a small portion of the gamma band in the present study.

### Desynchronized Theta Activity in Parietal and Central Areas in Typewriting

Conversely, for typewriting, a desynchronized activity was evident in the theta (4-8 Hz) and, to a lesser extent, in the alpha (8-12 Hz) range. The lower alpha (8-10 Hz) range has been found to reflect non-task related cognitive processes, such as expectancy, lower attention, and alertness (Klimesch, 1999; Klimesch, Pfurtscheller, & Schimke, 1992; Klimesch et al., 1994). Therefore, this finding could reflect the focus in finding the correct keys on the keyboard, typewriting with the index finger only, and not seeing the output appearing on the screen. The fact that the words produced by the participants did not appear on the screen may have affected the participants' attention in trying to write as correctly as possible. Typewriting with only the index finger may also have been unfamiliar and could have contributed to the need for increased attention.

The finding of desynchronized activity in the upper alpha (10-12 Hz) range, on the other hand, has been found to correlate with increasing task demands (Boiten, Sergeant, & Geuze, 1992). Within the alpha band, a desynchronization seems to imply that the oscillators within the band are no longer coupled and start to oscillate with different frequencies (Klimesch, 1999), implying that more areas of the brain are activated and multiple processes are occurring (Basar, Başar-Eroglu, Karakaş, & Schürmann, 2001). However, the desynchronized activity within the upper alpha (10-12 Hz) band observed here is apparent to a lesser extent, and is most likely due to increased attention and task demand because of the unfamiliar movements when typewriting with index finger only. An alternative interpretation of this rhythm could also be the movement mu (8-12 Hz) rhythm. This rhythm appears to desynchronize during movement (Cruikshank, Singhal, Hueppelsheuser, & Caplan, 2012). Whereas the participants were resting their elbow in the drawing and handwriting condition, thereby effectively reducing movement, more arm movements were present when they used the keyboard. However, since the theta, alpha and mu rhythm are nearby in frequencies, they may be difficult to distinguish from each other. Therefore, its relation to learning remains unclear.

## Different and Similar Activation Patterns in Handwriting and Drawing

The results reported above suggest that handwriting and drawing, are, just like typewriting and handwriting, two separate processes within the brain. However, these processes seem to be more similar to each other compared to typewriting, and our findings therefore both corroborate and extend the findings of van der Meer and van der Weel (2017). Compared to handwriting, drawing exhibited a desynchronized alpha (8-10 Hz) and beta (12-20 Hz) range activity. These findings suggest an increase in cognitive effort and attentive information processing (Boiten et al., 1992; Lopes da Silva, 1991), as well as the inclusion of motor acts (Pfurtscheller et al., 1996). In addition, the synchronized theta (4-8) band activity found in handwriting was also apparent in certain areas of the parietal regions. Therefore, as with handwriting, drawing seems to be ideal for facilitating learning.

Using a meta-analysis of brain imaging studies, Yuan and Brown (2015) found substantial overlap in activation patterns between handwriting and drawing, but a distinction in the left posterior parietal cortex. They further suggested that handwriting and drawing might employ the same underlying sensorimotor networks, but that some differences exist between them in the parietal areas. Thus, as found in the present study, the underlying processes within the brain involved in handwriting and drawing seem to support this notion. Studies have also shown that children, at an early age, manage to differentiate between these two (e.g., Otake, Treiman, & Yin, 2017; Treiman & Yin, 2011). The reason for this difference may not be surprising, considering the extensive involvement of language and letters in writing (Treiman & Yin, 2011), which drawing appears to lack.

As for the children, the same tendencies between handwriting, typewriting, and drawing could be observed, but they were far less evident compared to the adults. The reason for these less evident activation patterns could be due to more artifact-contaminated data in the children, resulting in fewer trials. EEG is particularly sensitive to movement, and young children are prone to movements. An alternative interpretation of these results may also be that the oscillatory frequency rhythms at 12-years old are not yet fully developed (e.g., Krause, Salminen, Sillanmaki, & Holopainen, 2001).

However, due to the observed tendencies, it thus seems likely that the differences observed in the adults, also are of importance for the children, if not more so. The specific type of experience seems to be of importance in causing the neural changes associated with learning. Thus, handwriting might support the development of these activation patterns in achieving the neural specificity in the brain, including the synchronized theta activity and theta-to-gamma frequency coupling found mainly in the adults in the present study. As children continue to improve their language and writing skills throughout adolescence, it is possible that these mechanisms are not fully developed at 12 years of age (Krause et al., 2001). Moreover, memory systems involving retrieval might be the last to mature within the brain (Krause et al., 2001), suggesting that further research within this field is necessary (Schneider, Abel, Ogiela, Middleton, & Maguire, 2016). However, our findings still provide support for handwriting practice providing beneficial neuronal activation patterns for learning. Therefore, maintaining the handwriting skill in school for optimal development seems to be of high importance. Thus, the initial hypotheses appear to be supported by the present findings.

## The Importance of Handwriting Practice in a Learning Environment

Whenever self-generated movements are included as a learning strategy, more of the brain gets stimulated, which results in the formation of more complex neural networks (van der Meer & van der Weel, 2017). It also appears that the movements related to keyboard writing do not activate these networks the same way that drawing and handwriting does. Besides, when a child produces individual handwritten letters, the results will be highly variable, leading to a better understanding (James, 2017; Li & James, 2016). The simultaneously spatiotemporal pattern from vision, motor commands and kinesthetic feedback provided through fine hand movements, is not apparent in typewriting, where only a single button press is required to produce the complete desired form (James, 2010; Longcamp et al., 2006; Vinci-Booher et al., 2016). Therefore, the ongoing replacement of handwriting by keyboard writing may in some respects seem ill-advised if this affects the learning process (Alonso, 2015; Mangen & Balsvik, 2016). The movement of handwriting may contribute to the brain's activation patterns in a state for learning, that does not seem to occur using a keyboard.

However, if the question of whether the implementation of digital devices in school is either helping or hindering learning, the answer is neither nor. In today's society, even though it is vital to maintain handwriting practice in school, it is also essential to keep up in the continuously developing digital world. Although young children should learn to manage to handwrite successfully, they should also learn to manage to write on a keyboard successfully (e.g., learn the touch method and transcribe information fast), depending on the context. The present study shows that the underlying brain electrical activity related to handwriting, typewriting, and drawing is different. Hence, being aware of when to use which strategy is vital, whether it is to learn new conceptual materials or to write a large number of essays. Even though there are underlying differences in the three strategies, handwriting, typewriting, and drawing are still cognitive tasks occurring within the brain, each serving their benefits.

## Limitations and Suggestions for Further Research

Even though the sample in the present study consisted of relatively even gender- and age-matched subjects within the two groups, it is important to note that inter-individual differences in oscillatory activity are as large as age-related differences (Klimesch, 1999). Also, some types of artifacts, e.g., eye blinks, may have an impact on theta power (Klimesch et al., 1994). Thus, this might affect the present findings. Moreover, the complex spatiotemporal pattern resulting in the EEG includes a large number of degrees of freedom (Lopes da Silva, 1991). The results should, therefore, be interpreted with some caution as we cannot be entirely sure that the signals are arising from the deep structures in the brain, or are caused by other confounding variables affecting the data. In addition, the theta (4-8 Hz), alpha (8-12 Hz), mu (8-12 Hz), and beta (12-20 Hz) rhythm are all nearby in frequencies and can be difficult to distinguish. This also highlights the importance to study each frequency individually.

With increasing technological development, it is vital that educators routinely evaluate the influences of learning environments (Stacy & Cain, 2015) for the long term implications. It is important to note that the present study was not attempted to suggest that we should prohibit digital devices in the classroom and go back to traditional handwriting in all levels of education. Instead, the purpose was to shed light on the topic and create awareness of which learning tradition has the best effect in what context. When using technological advances, it is important to ensure that handwriting practice remains a central activity in early letter learning, regardless if this occurs with a stylus and tablet or traditional paper and pencil (Vinci-Booher et al., 2016). As digital note-taking has undergone a vast transition, using a digital format today still allows the individual to handwrite notes, add drawings, and highlight text (Stacy & Cain, 2015). Therefore, the benefits from both writing methods can be implemented, and both students and teachers should be conscious of when to use which method, whether the aim is to produce long essay writings or to learn conceptual facts. Besides, learners will always vary in ability, which may affect which learning activities stimulate the use and/or effectiveness of cognitive processes (Arnold et al., 2017).

In conclusion, as van der Meer and van der Weel (2017) found evidence for a clear difference in underlying electrical brain activity between typewriting and drawing, this study adds to this knowledge, by showing that handwriting, typewriting, and drawing are each different processes. Nonetheless, handwriting and drawing seem to be more similar to each other, compared to typewriting. An optimal learning environment could, therefore, be to include the best from all disciplines, considering the strengths and support each of them offer, as suggested by Mueller and Oppenheimer (2014). This way, both cognitive development and learning efficiency can be strengthened, and all students and teachers can keep up with the technological development and digital challenges to come.

# References

Alonso, M. A. P. (2015). Metacognition and sensorimotor components underlying the process of handwriting and keyboarding and their impact on learning. An analysis from the perspective of embodied psychology. *Procedia - Social and Behavioral Sciences, 176*, 263-269. doi:10.1016/j.sbspro.2015.01.470

Arnold, K. M., Umanath, S., Thio, K., Reilly, W. B., McDaniel, M. A., & Marsh, E. J. (2017). Understanding the cognitive processes involved in writing to learn. *Journal of Experimental Psychology: Applied, 23*(2), 115-127. doi:10.1037/xap0000119

Basar, E., Başar-Eroglu, C., Karakaş, S., & Schürmann, M. (2001). Gamma, alpha, delta, and theta oscillations govern cognitive processes. *International Journal of Psychophysiology, 39*(2-3), 241-248. doi:10.1016/S0167-8760(00)00145-8

Benedek, M., Schickel, R. J., Jauk, E., Fink, A., & Neubauer, A. C. (2014). Alpha power increases in right parietal cortex reflects focused internal attention. *Neuropsychologia, 56*, 393-400. doi:10.1016/j.neuropsychologia.2014.02.010

Berens, S. C., & Horner, A. J. (2017). Theta rhythm: Temporal glue for episodic memory. *Current Biology, 27*(20), R1110-R1112. doi:10.1016/j.cub.2017.08.048

Berg, P., & Scherg, M. (1994). A multiple source approach to the correction of eye artifacts. *Electroencephalography and Clinical Neurophysiology, 90*(3), 229-241. doi:10.1016/0013-4694(94)90094-9

Bland, B. H., & Oddie, S. D. (2001). Theta band oscillation and synchrony in the hippocampal formation and associated structures: The case for its role in sensorimotor integration. *Behavioral Brain Research, 127*, 119-136. doi:10.1016/S0166-4328(01)00358-8

Boiten, F., Sergeant, J., & Geuze, R. (1992). Event-related desynchronization: The effects of energetic and computational demands. *Electroencephalography and Clinical Neurophysiology, 82*(4), 302-309.

Brown, C. M. (1988). Comparison of typing and handwriting in “two-finger typists”. *Proceedings of the Human Factors Society, 32*, 381-385. doi:10.1177/154193128803200533

Brownsett, S. L., & Wise, R. J. (2010). The contribution of the parietal lobes to speaking and writing. *Cerebral Cortex, 20*(3), 517-523. doi:10.1093/cercor/bhp120

Burke, J. F., Zaghloul, K. A., Jacobs, J., Williams, R. B., Sperling, M. R., Sharan, A. D., & Kahana, M. J. (2013). Synchronous and asynchronous theta and gamma activity during episodic memory formation. *Journal of Neuroscience, 33*(1), 292-304. doi:10.1523/JNEUROSCI.2057-12.2013

Buzsáki, G. (2006). *Rhythms of the brain*. New York, NY, US: Oxford University Press.

Canolty, R. T., Edwards, E., Dalal, S. S., Soltani, M., Nagarajan, S. S., Kirsch, H. E., . . . Knight, R. T. (2006). High gamma power is phase-locked to theta oscillations in human neocortex. *Science, 313*(5793), 1626-1628. doi:10.1126/science.1128115

Carter, S. P., Greenberg, K., & Walker, M. S. (2017). The impact of computer usage on academic performance: Evidence from a randomized trial at the United States Military Academy. *Economics of Education Review, 56*, 118-132. doi:10.1016/j.econedurev.2016.12.005

Clouter, A., Shapiro, K. L., & Hanslmayr, S. (2017). Theta phase synchronization is the glue that binds human associative memory. *Current Biology, 27*(20), 3143-3148 e3146. doi:10.1016/j.cub.2017.09.001

Cruikshank, L. C., Singhal, A., Hueppelsheuser, M., & Caplan, J. B. (2012). Theta oscillations reflect a putative neural mechanism for human sensorimotor integration. *Journal of Neurophysiology, 107*(1), 65-77. doi:10.1152/jn.00893.2010

Cunningham, A. E., & Stanovich, K. E. (1990). Early spelling acquisition: Writing beats the computer. *Journal of Educational Psychology, 82*(1), 159-162. doi:10.1037/0022-0663.82.1.159

Fears, N. E., & Lockman, J. J. (2018). How beginning handwriting is influenced by letter knowledge: Visual-motor coordination during children's form copying. *Journal of experimental Child Psychology, 171*, 55-70. doi:10.1016/j.jecp.2018.01.017

Ferree, T. C., Luu, P., Russell, G. S., & Tucker, D. M. (2001). Scalp electrode impedance, infection risk, and EEG data quality. *Clinical Neurophysiology, 112*(3), 536-544.

Fried, C. B. (2008). In-class laptop use and its effects on student learning. *Computers & Education, 50*(3), 906-914. doi:10.1016/j.compedu.2006.09.006

Fröhlich, F. (2016). *Network neuroscience*. London, England: Academic Press.

Fujioka, T., Mourad, N., He, C., & Trainor, L. J. (2011). Comparison of artifact correction methods for infant EEG applied to extraction of event-related potential signals. *Clinical Neurophysiology, 122*(1), 43-51. doi:10.1016/j.clinph.2010.04.036

Hoechstetter, K., Bornfleth, H., Weckesser, D., Ille, N., Berg, P., & Scherg, M. (2004). BESA source coherence: A new method to study cortical oscillatory coupling. *Brain Topography, 16*(4), 233-238. doi:10.1023/B:BRAT.0000032857.55223.5d

Hultin, E., & Westman, M. (2013). Early literacy practices go digital. *Literacy Information and Computer Education Journal (LICEJ), 4*(2), 1005-1013.

Ille, N., Berg, P., & Scherg, M. (2002). Artifact correction of the ongoing EEG using spatial filters based on artifact and brain signal topographies. *Journal of Clinical Neurophysiology, 19*(2), 113-124. doi:10.1097/00004691-200203000-00002

James, K. H. (2010). Sensori-motor experience leads to changes in visual processing in the developing brain. *Developmental Science, 13*(2), 279-288. doi:10.1111/j.1467-7687.2009.00883.x

James, K. H. (2017). The importance of handwriting experience on the development of the literate brain. *Current Directions in Psychological Science, 26*(6), 502-508. doi:10.1177/0963721417709821

James, K. H., & Engelhardt, L. (2012). The effects of handwriting experience on functional brain development in pre-literate children. *Trends in Neuroscience and Education, 1*(1), 32-42. doi:10.1016/j.tine.2012.08.001

Kay, R. H., & Lauricella, S. (2011). Exploring the benefits and challenges of using laptop computers in higher education classrooms: A formative analysis. *Canadian Journal of Learning and Technology, 37*(1). doi:10.21432/T2S598

Kersey, A. J., & James, K. H. (2013). Brain activation patterns resulting from learning letter forms through active self-production and passive observation in young children. *Frontiers in Psychology, 4*, 567. doi:10.3389/fpsyg.2013.00567

Kiefer, M., Schuler, S., Mayer, C., Trumpp, N. M., Hille, K., & Sachse, S. (2015). Handwriting or typewriting? The influence of pen- or keyboard-based writing training on reading and writing performance in preschool children. *Advances in Cognitive Psychology, 11*(4), 136-146. doi:10.5709/acp-0178-7

Kiewra, K. A. (1985). Investigating notetaking and review: A depth of processing alternative. *Educational Psychologist, 20*(1), 23-32. doi:10.1207/s15326985ep2001_4

Klimesch, W. (1996). Memory processes, brain oscillations and EEG synchronization. *International Journal of Psychophysiology, 24*(1-2), 61-100. doi:10.1016/S0167-8760(96)00057-8

Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: A review and analysis. *Brain Research Reviews, 29*(2-3), 169-195. doi:10.1016/S0165-0173(98)00056-3

Klimesch, W., Doppelmayr, M., Yonelinas, A., Kroll, N. E., Lazzara, M., Roehm, D., & Gruber, W. (2001). Theta synchronization during episodic retrieval: Neural correlates of conscious awareness. *Cognitive Brain Research, 12*(1), 33-38. doi:10.1016/S0926-6410(01)00024-6

Klimesch, W., Pfurtscheller, G., & Schimke, H. (1992). Pre- and post-stimulus processes in category judgement tasks as measured by event-related desynchronization (ERD). *Journal of Psychophysiology, 6*(3), 185-203.

Klimesch, W., Schimke, H., Doppelmayr, M., Ripper, B., Schwaiger, J., & Pfurtscheller, G. (1996). Event-related desynchronization (ERD) and the Dm-effect: Does alpha desynchronization during encoding predict later recall performance? *International Journal of Psychophysiology, 24*(1-2), 47-60. doi:10.1016/S0167-8760(96)00054-2

Klimesch, W., Schimke, H., & Schwaiger, J. (1994). Episodic and semantic memory: An analysis in the EEG theta and alpha band. *Electroencephalography and Clinical Neurophysiology, 91*(6), 428-441. doi:10.1016/0013-4694(94)90164-3

Krause, C. M., Salminen, P. A., Sillanmaki, L., & Holopainen, I. (2001). Event-related desynchronization and synchronization during a memory task in children. *Clinical Neurophysiology, 12*(12), 2233-2240. doi:10.1016/S1388-2457(01)00684-8

Li, J. X., & James, K. H. (2016). Handwriting generates variable visual output to facilitate symbol learning. *Journal of Experimental Psychology: General, 145*(3), 298-313. doi:10.1037/xge0000134

Longcamp, M., Anton, J. L., Roth, M., & Velay, J. L. (2003). Visual presentation of single letters activates a premotor area involved in writing. *NeuroImage, 19*(4), 1492-1500. doi:10.1016/s1053-8119(03)00088-0

Longcamp, M., Boucard, C., Gilhodes, J. C., & Anton, J. L. (2008). Learning through hand- or typewriting influences visual recognition of new graphic shapes: Behavioral and functional imaging evidence. *Journal of Cognitive Neuroscience, 20*(5), 802-815. doi:10.1162/jocn.2008.20504

Longcamp, M., Boucard, C., Gilhodes, J. C., & Velay, J. L. (2006). Remembering the orientation of newly learned characters depends on the associated writing knowledge: A comparison between handwriting and typing. *Human Movement Science, 25*(4-5), 646-656. doi:10.1016/j.humov.2006.07.007

Longcamp, M., Zerbato-Poudou, M. T., & Velay, J. L. (2005). The influence of writing practice on letter recognition in preschool children: A comparison between handwriting and typing. *Acta Psychologica, 119*(1), 67-79. doi:10.1016/j.actpsy.2004.10.019

Lopes da Silva, F. H. (1991). Neural mechanisms underlying brain waves: From neural membranes to networks. *Electroencephalography and Clinical Neurophysiology, 79*(2), 81-93. doi:10.1016/0013-4694(91)90044-5

Luck, S. J. (2005). *An introduction to the event-related potential technique*. Cambridge, MA: MIT Press.

Mangen, A., & Balsvik, L. (2016). Pen or keyboard in beginning writing instruction? Some perspectives from embodied cognition. *Trends in Neuroscience and Education, 5*(3), 99-106. doi:10.1016/j.tine.2016.06.003

Menon, V., & Desmond, J. E. (2001). Left superior parietal cortex involvement in writing: Integrating fMRI with lesion evidence. *Cognitive Brain Research, 12*(2), 337-340. doi:10.1016/S0926-6410(01)00063-5

Mueller, P. A., & Oppenheimer, D. M. (2014). The pen is mightier than the keyboard: Advantages of longhand over laptop note taking. *Psychological Science, 25*(6), 1159-1168. doi:10.1177/0956797614524581

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia, 9*(1), 97-113. doi:10.1016/0028-3932(71)90067-4

Osipova, D., Takashima, A., Oostenveld, R., Fernandez, G., Maris, E., & Jensen, O. (2006). Theta and gamma oscillations predict encoding and retrieval of declarative memory. *Journal of Neuroscience, 26*(28), 7523-7531. doi:10.1523/JNEUROSCI.1948-06.2006

Otake, S., Treiman, R., & Yin, L. (2017). Differentiation of writing and drawing by U.S. two- to five-year-olds. *Cognitive Development, 43*, 119-128. doi:10.1016/j.cogdev.2017.03.004

Patterson, R. W., & Patterson, R. M. (2017). Computers and productivity: Evidence from laptop use in the college classroom. *Economics of Education Review, 57*, 66-79. doi:10.1016/j.econedurev.2017.02.004

Perrin, F., Pernier, J., Bertrand, O., & Echallier, J. F. (1989). Spherical splines for scalp potential and current density mapping. *Electroencephalography and Clinical Neurophysiology, 72*(2), 184-187.

Pfurtscheller, G., & Aranibar, A. (1977). Event-related cortical desynchronization detected by power measurements of scalp EEG. *Electroencephalography and Clinical Neurophysiology, 42*(6), 817-826. doi:10.1016/0013-4694(77)90235-8

Pfurtscheller, G., & Lopes da Silva, F. H. (1999). Event-related EEG/MEG synchronization and desynchronization: Basic principles. *Clinical Neurophysiology, 110*(11), 1842-1857. doi:10.1016/S1388-2457(99)00141-8

Pfurtscheller, G., Neuper, C., & Mohl, W. (1994). Event-related desynchronization (ERD) during visual processing. *International Journal of Psychophysiology, 16*(2-3), 147-153.

Pfurtscheller, G., Stancak, A. J., & Neuper, C. (1996). Event-related synchronization (ERS) in the alpha band - an electrophysiological correlate of cortical idling: A review *International Journal of Psychophysiology, 24*(1-2), 39-46. doi:10.1016/S0167-8760(96)00066-9

Picton, T. W., Bentin, S., Berg, P., Donchin, E., Hillyard, S. A., Johnson, R. J., . . . Taylor, M. J. (2000). Guidelines for using human event-related potentials to study cognition: Recording standards and publication criteria. *Psychophysiology, 37*, 127-152.

Planton, S., Longcamp, M., Péran, P., Démonet, J.-F., & Jucla, M. (2017). How specialized are writing-specific brain regions? An fMRI study of writing, drawing and oral spelling. *Cortex, 88*, 66-80. doi:10.1016/j.cortex.2016.11.018

Raghavachari, S., Kahana, M. J., Rizzuto, D. S., Caplan, J. B., Kirschen, M. P., Bourgeois, B., . . . Lisman, J. E. (2001). Gating of human theta oscillations by a working memory task. *Journal of Neuroscience, 21*(9), 3175-3183.

Sana, F., Weston, T., & Cepeda, N. J. (2013). Laptop multitasking hinders classroom learning for both users and nearby peers. *Computers & Education, 62*, 24-31. doi:10.1016/j.compedu.2012.10.003

Scherg, M., & Berg, P. (1991). Use of prior knowledge in brain electromagnetic source analysis. *Brain Topography, 4*(2), 143-150. doi:10.1007/BF01132771

Schneider, J. M., Abel, A. D., Ogiela, D. A., Middleton, A. E., & Maguire, M. J. (2016). Developmental differences in beta and theta power during sentence processing. *Developmental Cognitive Neuroscience, 19*, 19-30. doi:10.1016/j.dcn.2016.01.001

Simes, R. J. (1986). An improved Bonferroni procedure for multiple tests of significance. *Biometrika, 73*, 751-754. doi:10.1093/biomet/73.3.751

Singer, W. (1993). Synchronization of cortical activity and its putative role in information processing and learning. *Annual Review og Physiology, 55*(1), 349-374.

Smoker, T. J., Murphy, C. E., & Rockwell, A. K. (2009). Comparing memory for handwriting versus typing. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 53*(22), 1744-1747. doi:10.1518/107118109X12524444081755

Solomon, E. A., Kragel, J. E., Sperling, M. R., Sharan, A., Worrell, G., Kucewicz, M., . . . Kahana, M. J. (2017). Widespread theta synchrony and high-frequency desynchronization underlies enhanced cognition. *Nature Communications, 8*(1), 1704. doi:10.1038/s41467-017-01763-2

Stacy, E. M., & Cain, J. (2015). Note-taking and handouts in the digital age. *American Journal of Pharmaceutical Education, 79*(7), 107. doi:10.5688/ajpe797107

Thibon, L. S., Barbier, G., Vilain, C., Sawallis, T. R., Gerber, S., & Kandel, S. (2018). Investigating how children produce rotation and pointing movements when they learn to write letters. *Human Movement Science*. doi:10.1016/j.humov.2018.04.008

Treiman, R., & Yin, L. (2011). Early differentiation between drawing and writing in Chinese children. *Journal of experimental Child Psychology, 108*(4), 786-801. doi:10.1016/j.jecp.2010.08.013

Tucker, D. M. (1993). Spatial sampling of head electrical fields: The geodesic sensor net. *Electroencephalography and Clinical Neurophysiology, 87*(3), 154-163. doi:10.1016/0013-4694(93)90121-B

Tucker, D. M., Liotti, M., Potts, G. F., Russell, G. S., & Posner, M. I. (1994). Spatiotemporal analysis of brain electrical fields. *Human Brain Mapping, 1*(2), 134-152. doi:10.1002/hbm.460010206

van der Meer, A. L. H., & van der Weel, F. R. R. (2017). Only three fingers write, but the whole brain works: A high-density EEG study showing advantages of drawing over typing for learning. *Frontiers in Psychology, 8*(706). doi:10.3389/fpsyg.2017.00706

Velasques, B., Machado, S., Portella, C. E., Silva, J. G., Basile, L. F., Cagy, M., . . . Ribeiro, P. (2007). Electrophysiological analysis of a sensorimotor integration task. *Neuroscience letters, 426*(3), 155-159. doi:10.1016/j.neulet.2007.08.061

Vinci-Booher, S., James, T. W., & James, K. H. (2016). Visual-motor functional connectivity in preschool children emerges after handwriting experience. *Trends in Neuroscience and Education, 5*(3), 107-120. doi:10.1016/j.tine.2016.07.006

Yuan, Y., & Brown, S. (2015). Drawing and writing: An ALE meta-analysis of sensorimotor activations. *Brain and Cognition, 98*, 15-26. doi:10.1016/j.bandc.2015.05.004

# Appendices

## Appendix A

NTNU
Kunnskap for en bedre verden

Forespørsel om deltakelse i forskningsprosjekt:

### EEG-studium av viktigheten av håndskrift i forhold til læring

Vi gjennomfører et prosjekt i forbindelse med masteroppgave og vil undersøke forskjeller i hjerneaktivitet i forhold til læring. Bakgrunnen for oppgaven er inspirert av tidligere forskning av Audrey van der Meer og Ruud van der Weel, som fant forskjeller i hjerneaktivitet mellom betingelsene tegning, skriving og beskriving i en EEG-studie. Denne oppgaven vil inkludere flere betingelser, men vil legge hovedvekten på forskjellene mellom tasting på tastatur og håndskrift med penn, og se hvilke av disse betingelsene som egner seg best for læring. Tidligere forskning har vist at koblingen mellom persepsjon og motorikk er en fordel for både utvikling og læring. I og med at både lesing og skriving blir mer og mer digitalisert, er det viktig å undersøke langtidsimplikasjonene.

Prosjektet er basert på frivillig deltakelse, og du/dere kan når som helst trekke dere underveis og be om å få slettet data om deres barn uten begrunnelse. Dere er ikke forpliktet til å gjennomføre og en eventuell avbrytning vil ikke få konsekvenser. Av kontrollhensyn vil datamaterialet, bestående av hjerneregistering, bli oppbevart på en forsvarlig måte ved prosjektslutt (mai 2019) og det vil kun være prosjektmedarbeidere med taushetsplikt som har tilgang til det. Forsøkspersoner må være høyrehendte, men dersom det er ønskelig kan venstrehendte bli inkludert ved en senere anledning.

Eksperimentet vil ta omtrent 45 minutter (i tillegg til litt forberedelsestid) og vil foregå ved Nevrovitenskapelig utviklingslaboratorium, Psykologisk institutt, Dragvoll, NTNU. Barnet vil ha på seg en helt ufarlig hette med små sensorer og ledninger mens han/hun utfører ulike skrive- og tegneoppgaver i et rom. Hvis barnet ikke trives med situasjonen, blir forsøket avsluttet med en gang. Vi er to masterstudenter som kommer til å teste deltakerne og vi er svært fleksible på tidspunkt for testinger. Dersom du kunne tenke deg å la din sønn/datter delta, kan du gjerne ta kontakt med:

Eva Ose Askvik
+47 99562328
evaoa@stud.ntnu.no

## Appendix B

Vennligst oppgi hvilken hånd du foretrekker i følgende gjøremål ved å sette et kryss i passende kolonne.

| | |
|---|---|
| VV | du vil *svært sjelden* bruke noe annet enn venstre hånd |
| V | du *foretrekker* å bruke venstre hånd |
| E | det er *samme hvilken* hånd du bruker |
| H | du *foretrekker* å bruke høyre hånd |
| HH | du vil *svært sjeldens* bruke noe annet enn høyre hånd |

I noen tilfeller vil gjøremålene kreve bruk av begge hender, og det vil da stå i parentes hva vi er ute etter.

Vennligst gjør et forsøk på å "prøve ut" oppgavene før du svarer og ikke bare anta at du vil bruke samme hånd gjennom alle gjøremålene.

| | | VV | V | E | H | HH |
|---|---|---|---|---|---|---|
| 1. | Kaste en dartpil | | | | | |
| 2. | Bruk av strykejern | | | | | |
| 3. | Krølle sammen papir | | | | | |
| 4. | Skru av en flaskekork | | | | | |
| 5. | Ta av tape (fra rullen) | | | | | |
| 6. | Male et bilde | | | | | |
| 7. | Pusse tennene | | | | | |
| 8. | Bruk av bordtennisracket | | | | | |
| 9. | Tegning | | | | | |
| 10. | Snu om side i bok | | | | | |
| 11. | Pusse sko | | | | | |
| 12. | Kaste ball | | | | | |
| 13. | Gre håret | | | | | |
| 14. | Skjære brød | | | | | |
| 15. | Bruk av vinåpner | | | | | |
| 16 | Tenne fyrstikk | | | | | |
| 17. | Bruk av hammer | | | | | |
| 18 | Sage ved (hånd på sagen) | | | | | |
| 19. | Tømme ut vann | | | | | |
| 20. | Langkost (øverste hånd) | | | | | |
| 21. | Spade (øverste hånd) | | | | | |
| 22. | Rake (øverste hånd) | | | | | |
| 23. | Bruk av øks (hånd nærmest blad) | | | | | |
| 24. | Sykkelpumpe (hånd du pumper med) | | | | | |
| 25. | Knyte skolisse (lager først knute med) | | | | | |
| 26. | Sparke ball (fot) | | | | | |
| 27. | Hinke (fot) | | | | | |
| 28. | Folde hendene (hvilken tommel øverst?) | | | | | |
| 29. | Legge armene i kors (hvilken hånd øverst?) | | | | | |
| 30. | Hvilken hånd skriver du med | | | | | |

Poengberegning:

| | |
|---|---|
| VV | To poeng for venstre |
| V | Et poeng for venstre |
| E | Et poeng for venstre og et poeng for høyre |
| H | Et poeng for høyre |
| HH | To poeng for høyre |

Lateralitetskvotienten beregnes slik:

$$\text{LK} = \frac{(antall\ poeng\ for\ høyre) - (antall\ poeng\ for\ venstre)}{Poengsum\ totalt}$$

**Appendix C**

# SAMTYKKEERKLÆRING

**Prosjekttittel:** EEG-studium av hjerneaktivitet hos voksne

Jeg har fått muntlig informasjon om eksperimentet og er villig til å delta i prosjektet.

……………………… ……………….. ……………………………………

Sted Dato Underskrift

**Appendix D**

# SAMTYKKEERKLÆRING

**Prosjekttittel:** En EEG-studie av viktigheten av håndskrift i forhold til læring

Prosjektet går ut på å undersøke forskjeller i hjerneaktivitet mellom ulike betingelser, men vil legge hovedvekten på forskjellene mellom tasting på tastatur og håndskrift med penn, og se hvilke av disse betingelsene som egner seg best for læring. Barnet vil ha på seg en helt ufarlig hette med små sensorer og ledninger mens han/hun utfører ulike skrive- og tegneoppgaver i et rom. Prosjektet er basert på frivillig deltakelse, og du/dere kan når som helst trekke dere underveis og be om å få slettet data om deres barn uten begrunnelse. Av kontrollhensyn vil datamaterialet, bestående av hjerneregistering, bli oppbevart på en forsvarlig måte ved prosjektslutt (mai 2019) og det vil kun være prosjektmedarbeidere med taushetsplikt som har tilgang til det.

Jeg har mottatt infoskriv og supplerende muntlig informasjon om eksperimentet og er villig til å delta i prosjektet.

……………………… ……………….. …………………………………

Sted Dato Foresattes underskrift

……………………… ……………….. …………………………………

Sted Dato Barnets underskrift

Fornavn Etternavn

Uppgavens tittel

NTNU
Norwegian University of
Science and Technology