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Being creative to learn better - An EEG study on creativity and learning in adults

Master's thesis in Læring - hjerne, adferd, omgivelser
Supervisor: Audrey van der Meer
May 2019

Master's thesis

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Science and Technology

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NTNU
Kunnskap for en bedre verden

Abstract

Are creativity and learning connected? And is creating your own drawings and texts compared to mere copying, more beneficial to these processes? The study investigated brain electrical activity using electroencephalogram (EEG) in adults while they were drawing and describing a given word, and copying a pre-made drawing or short description using a touch screen and a digital pen. Individual and averaged Temporal Spectral Evolution (TSE) analyses showed more widespread brain oscillations when the participants were drawing and describing as opposed to copying, pointing to an activation of more and larger neural networks which have been proposed to be beneficial to learning, as well as to be important to creativity. Copying drawings and text elicited more beta and gamma event-related desynchronization (ERD) in sensorimotor areas, which indicated more motor activity. In contrast, when the participants were creating their own drawings and descriptions, theta and gamma event-related synchronization (ERS) was observed, and such oscillatory activity can be attributed to higher cognitive processes beneficial to both learning and creativity. Alpha ERD was observed when drawing and describing, and this was linked to enhanced focused attention on the task and memory retrieval. The findings indicated that creativity and learning are complex processes that develop over time, and it was concluded that creativity cannot easily be separated from other brain activity, particularly that seen in learning processes. It was proposed to include more creative tasks in learning situations to facilitate learning in the best possible way.

Sammendrag

Fins det en kobling mellom kreativitet og læring, og er det mer gunstig for disse prosessene å lage egne tegninger og tekster fremfor å kopiere andres? Denne studien undersøkte hjerneaktivitet ved hjelp av elektroencefalogram (EEG) hos voksne når de tegnet og beskrev et ord, samt kopierte en tegning eller kort beskrivelse ved hjelp av en datamaskin med berøringsskjerm og en tilhørende digital penn. Temporal Spectral Evolution (TSE)-analyser på både individuelt og gjennomsnittsnivå ble brukt for å analysere dataene, og fant i større grad spredte oscillasjoner når forsøkspersonene tegnet og beskrev fremfor kopierte, hvis pekte på aktivering av større og flere nevrale nettverk som er gunstig for både læring og kreative prosesser. Kopiering av tegninger og tekst viste til mer beta og gamma desynkronisering (event-related desynchronization, ERD) i sensomotoriske områder, som indikerte mer motorisk aktivitet, mens det ble funnet både gamma og theta synkronisering (event-related synchronization, ERS) når forsøkspersonene tegnet og beskrev, der gamma og theta ERS har blitt relatert til høyere kognitive prosesser knyttet til både læring og kreativitet. Det ble funnet alfa ERD når forsøkspersonene tegnet og beskrev, og dette ble knyttet til økt oppgavefokus, oppmerksomhet og hukommelsesprosesser. Funnene i studien pekte på kreativitet og læring som komplekse prosesser som utfoldet seg over tid, og det ble konkludert med at kreativitet ikke lett kan separeres fra annen hjerneaktivitet, deriblant særlig læring. Det ble foreslått å innlemme mer kreative oppgaver i læringssituasjoner for å fasilitere læring på best mulig måte.

Acknowledgements

I am very grateful to my supervisor Prof. Audrey van der Meer and co-supervisor Prof. Ruud van der Weel for the opportunity to work on my master thesis in their lab, the Developmental Neuroscience Laboratory (Nu-lab) at the Norwegian University of Science and Technology (NTNU). Van der Meer and van der Weel have provided me with tremendous support, supervision and valuable feedback during my research that I have appreciated greatly. I also wish to thank the resident programmer Erik Bjørgen and the PhD-students Seth Bonsu Agyei, Kenneth Vilhelmsen and Regine Slinning for their excellent advice and not to mention technical support.

I was very thankful for working alongside my fellow master students Eva Ose Askvik and Stefania Rasulo, whom were excellent colleagues providing not only good company and much needed laughs, but also great assistance in both conducting the experiment and discussing the results. I also wish to thank my parents for their endless support and motivation not only this year while I was working on my thesis, but throughout my entire education.

Finally, much appreciation goes out to everyone who participated in this study – without them, this could not have been done.

Trondheim, May 2019

Elisabeth Deilhaug

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1 Introduction

Creativity is highly sought after in our modern society, from big tech companies wishing to improve their products, to scientists coming up with new remedies to our troubles, to artists decorating both corporate and private spaces. While the definition of creativity remains elusive and abstract as it can be relative to the task at hand (Dietrich, 2007, Dietrich 2019a), it has in research on creative cognition commonly been defined as the ability to produce novel and useful ideas (Stein, 1953). Research on creativity has typically investigated two different types of creativity: "Little C" and "Big C", where the former refers to an everyday type of creativity which most people possess, and the latter to the culturally significant works attributed to creative geniuses (Kaufmann & Beghetto, 2009). As "Big C" is reserved for a few people who have dedicated large amounts of time to hone their skill, most neuropsychological research, including the present study, investigates a more common type of creativity akin to that of "Little C".

Research on creativity has produced varying results and has received criticism for over-simplifying what creativity is, and at the same time being inconsistent for applying a wide variety of methods to measure the same thing (Dietrich, 2007; Dietrich, 2019b; Dietrich and Kanso, 2010; Pidgeon, Grealy, Duffy, Hay, McTeague, Vuletic, Coyle, & Gilbert, 2016). While the traditional idea of creativity being located in the right hemisphere has lost traction in light of new neuroimaging research, and studies rather emphasise the widespread neural activation during creativity, it is widely accepted that executive functions of the prefrontal cortex, such as planning, working memory, and cognitive flexibility are necessary (Dietrich, 2004; Kowatari, Lee, Yamamura, Nagamori, Levy, Yamane, & Yamamoto, 2009). Research on divergent thinking has been especially popular in neuroimaging studies, and divergent thinking is a concept that was first coined by Guilford (1950), who defined it as the ability to generate multiple solutions to an open-ended problem (Guilford, 1967). Modern research on divergent thinking creativity commonly uses the Alternate Uses Test (Guilford, 1967), which requires the participant to come up with untraditional, alternate uses for commonplace objects (e.g., a brick). Utilising this test, studies using electroencephalogram (EEG) have typically found increased oscillatory synchrony (Benedek, Bergner, Könen, Fink, & Neubauer, 2011; Fink, Grabner, Benedek, & Neubauer, 2006; Jauk, Benedek, & Neubauer, 2012), and to a lesser degree,

decreased oscillatory synchrony in the alpha frequency band (Razumnikova, 2007; Razumnikova, Vold, & Tarasova, 2009), predominantly in the prefrontal cortex, as well as in parieto-occipital areas (Fink & Benedek, 2014). These differences are important as alpha synchronization reflects cortical inhibition, whereas alpha desynchronization is seen when the participant is focused on the task at hand (Pfurtscheller & Lopes da Silva, 1999). Studies using neuroimaging tools such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) reveal a more consistent picture, reporting activation of prefrontal regions (Benedek, Jauk, Fink, Koschutnig, Reishofer, Ebner, & Neubauer, 2014; Fink, Grabner, Benedek, Reishofer, Hauswirth, Fally, Neuper, Ebner, & Neubauer, 2009; Howard-Jones, Blakemore, Samuel, Summer, & Claxton 2005).

Insight, the "aha!" or "Eureka!" experience of finding the solution to a given problem, has also been investigated in studies on creativity. This type of creativity contrasts with the aforementioned divergent thinking, as it is more convergent in nature with an aim to find the right solution, rather than several untraditional ones. Studies on insight report synchronized gamma bursts right before the insight solution, frontal alpha desynchronization, and parietal alpha synchronization indicating an activation of the prefrontal cortex and the suppression of irrelevant information from the visual cortex (Danko, Starchenko, & Bechtereva, 2003; Jung-Beeman, Bowden, Haberman, Frymiare, Arambel-Liu, Greenblatt, Reber, & Kounios, 2004; for a review, see Sprugnoli, Rossi, Emmendorfer, Rossi, Liew, Tatti, di Lorenzo, Pascual-Leone, & Santarnecchi, 2017). Studies on creativity have also examined musical creativity and improvisation, where participants typically are asked to mentally improvise a song or dance, as well as recall one that is known. These studies have found increases in frontal alpha synchronization (Fink, Graif, & Neubauer, 2009; Stevens Jr. & Zabelina, 2019) and dissociated activity in the lateral prefrontal cortex (Limb & Braun, 2008; Liu, Chow, Xu, Erkkinen, Swett, Eagle, Rizik-Baer, & Braun, 2012) during improvisation. These findings were linked to defocused attention and inhibition of self-monitoring functions, which allow random and irrelevant thoughts to emerge.

The research on creativity listed above has predominantly focused on creativity as a sudden change from a "not creative" state. An ecological perspective on creativity is offered by Withagen and van der Kamp (2018). Their perspective is informed by Gibson's (1979) theory of affordances, which refers to how the environment offers the animal possibilities to act. Behaviour is thus adapted to the situation or material at hand. Withagen and van der Kamp (2018) argue that a creative idea does not necessarily have to first occur in the mind to

subsequently be imposed on the material, but that creativity rather emerges and develops in contact with the material. Put differently, creativity develops over time and can be seen in the process of creating.

A study by Nagornova (2007) compared two relatively creative conditions with two less creative conditions, where the participants were asked to draw a picture thought up by themselves (creative), draw given objects or concepts in an original manner ("in a way no one else would draw") (creative), draw from memory a picture consisting of a set of geometric figures shown prior to the task (non-creative), and draw geometric figures (non-creative). Using EEG, it was reported that the creative compared to the non-creative conditions elicited high-beta band power increases in the frontal and temporal areas, gamma power increases in the temporal and parietal areas of the right hemisphere, as well as high-alpha band power changes in temporal, frontal and centro-parietal areas. Comparing the two creative conditions, greater high-frequency power and an increase in alpha synchronization was found when drawing a given object in a unique manner compared to drawing an original picture, and this was assumed to be a sign of greater creative performance: the participants had a stereotypical (non-creative) image of the given object in mind and could thus proceed to create a more unique version, compared to coming up with an original image of their own choosing where they had to decide for themselves whether it was creative or not. It was argued that the high-frequency oscillations in the creative conditions may be caused by creative activity, an increase in top-down control, and the activation of visual memory. The desynchronized alpha activity observed when creating original pictures compared to making unique renditions of a given object, was suggested to reflect activation of focused attention during an active mental search for original pictures to draw as well as at the same time assessing the originality of these.

Using fMRI, Shah, Erhard, Ortheil, Kaza, Kessler, & Lotze (2013) focused on creative versus non-creative writing. The participants were asked to read a short text, copy by hand the first part of the given text, brainstorm about creative continuation of the text, and write a creative continuation. Brainstorming showed involvement of fronto-parieto-temporal brain activity, where especially the left dorsolateral prefrontal cortex (dlPFC) and dorsal anterior cingulate cortex (dACC) were linked to planning the story. The dlPFC, in particular, has been connected to creativity in other studies due to its role in planning and self-censorship (Dietrich & Kanso, 2010; Kowatari et al., 2009). In contrast to copying, creative writing showed activation in the left superior temporal gyrus (STG) and the left inferior frontal gyrus (IFG),

which are areas associated with semantic integration, memory retrieval, free association, and spontaneous cognition (Shah et al., 2013).

The above studies investigated creativity, and there was an overlap in brain areas related to creativity and memory. Memory and learning are cognitive processes that are closely related in function and neuroanatomy (Purves, Augustine, Fitzpatrick, Hall, LaMantia, McNamara, & Williams, 2004), and a possible link between creative tasks and learning processes will thus be investigated. As this article will focus on EEG and oscillatory activity, some functions of oscillatory activity will be outlined before addressing relevant studies on learning.

Event-related synchronization (ERS) and event-related desynchronization (ERD) are due to increases or decreases, respectively, in underlying neuronal populations (Pfurtscheller and Lopes da Silva, 1999), and the function of desynchronized and synchronized oscillatory activity varies depending on the frequency (Hanslmayr, Staresina, & Bowman 2016; Lam, Schoffelen, Uddén, Hultén, & Hagoort, 2016; Pfurtscheller and Lopes da Silva, 1999). This can be seen in alpha (8-12 Hz) activity, where synchronization has been linked to both cortical idling (Pfurtscheller, Stancák Jr., & Neuper 1996) and, more recently, top-down inhibitory cognitive processes (Klimesch, Sauseng, & Hanslmayr, 2007) that are thought to functionally inhibit task-irrelevant brain areas in order to gate information to and from relevant areas to optimize task performance (Jensen & Mazaheri, 2010). Desynchronized alpha activity, on the other hand, is observed in a wide variety of tasks where the participant is attentive or engaged in semantic processing (Klimesch, 1999; Pfurtscheller and Lopes da Silva, 1999). Alpha desynchronization is considered beneficial for memory and learning processes, especially when combined with synchronized theta (4-7 Hz) activity as this is linked to long-term memory encoding and retrieval (Khader, Jost, Ranganath, & Rösler, 2010; Klimesch, 1999; Klimesch, Fellinger, & Freunberger, 2011; Sauseng, Klimesch, Schabus, & Doppelmayr, 2005). Similarly, the combination of synchronized theta and gamma has also been proposed as beneficial to memory retrieval and encoding (Hanslmayr et al., 2016; Lisman and Jensen, 2013; Osipova, Takashima, Oostenveld, Fernández, Maris, & Jensen, 2006; Wang, 2010): Gamma has been related to various cognitive processes such as perceptual binding, memory encoding, and object and language recognition (Fries, 2009; Herrmann, Munk, & Engel, 2004; Herrmann, Fründ, & Lenz, 2010; Osipova et al., 2006), while the slower theta waves provide sufficiently large time windows for long-term potentiation to occur (Clouter, Shapiro, & Hanslmayr, 2017).

Drawing and handwriting both require complex sensorimotor skills (Penketh, 2011), and is proposed to involve similar patterns of brain activity (Potgieser, van der Hoorn, & de Jong, 2015). The Generative Theory of Drawing Construction was proposed by van Meter and Garner (2005), which states that drawing has beneficial effects on learning new content as one has to integrate different skills and mental processes: first, one has to select key elements from a text (and alternatively an author-provided illustration) to represent in a drawing; second, one has to organize the selected elements to construct a verbal representation of the text, while making associative connections between old (prior knowledge) or generated (new) internal models of the selected elements; and finally, integrate the verbal (and non-verbal if an illustration already is provided) content in a mental model of the illustration. Research shows that verbatim notetaking (e.g. copying text) involves shallow cognitive processing that is less beneficial to learning (Kiewra, 1987), and negatively impact performance on comprehension text compared to non-verbatim techniques such as paraphrasing or summarizing (Jonassen, 1984; Slotte & Lonka, 1999). Similarly, it has been suggested that drawing fosters encoding similar to non-verbatim notetaking: A study by Wammes, Meade and Fernandes (2017) investigated the potential learning benefits of drawing compared to verbatim and non-verbatim writing. In three similar experiments, undergraduate students were given definitions of terms (scientific and fictitious) and asked to verbatim copy the definitions (replaced with paraphrasing the definition in the third experiment) or draw a picture representing the term. The authors found that drawing, as well as paraphrasing, were effective encoding strategies compared to copying the definitions verbatim, and thus more beneficial to learning. Similar results were found by van Meter, Aleksic, Schwartz and Garner (2006) upon testing American fourth and sixth graders, where the children asked to make drawings representing what they had learnt from two texts scored higher on two subsequent tests (recognition and problem solving) compared to children who were given an illustration to look at, but did not draw themselves.

A study on drawing and typing and their potential effects on learning was conducted by van der Meer and van der Weel (2017). Using EEG, they investigated differences in brain activity when typing a word on a keyboard, describing a word using a keyboard, and drawing a word using a digital pen. Comparing typing and drawing, they found that drawing elicited event-related desynchronizations (ERD) in the theta and alpha oscillatory range in parietal and occipital areas, which was linked to sensorimotor integration and activation of large neural networks and cortical areas associated with information processing, thus putting the brain in an optimal state for learning. Additionally, the authors found event-related synchronization (ERS)

in the upper alpha, beta, and gamma oscillatory frequencies in the central and frontal brain regions particularly in the ideation phase (the first 2-3 seconds of each trial) when the participants were describing. While the authors considered this activation a bit unclear, it was proposed to indicate the involvement of higher cognitive thought processes when the participants attempted to figure out how to best describe the given word.

Additional research on the interplay between drawing and learning was conducted by Schmeck, Mayer, Opfermann, Pfeiffer and Leutner (2014). The authors investigated effects on learning when drawing while reading scientific texts. In two experiments, they asked German 8th graders to read a scientific text (control condition), combine reading the text and create drawings to represent the content, and in the second experiment, draw with a provided image as a visual aid. All students were later given comprehension and drawing tests, where the students who had been drawing in addition to reading, scored significantly higher on both tests than the students in the control group. While the students that had been drawing both required longer time and reported higher invested mental effort than the controls, they still performed better than the control group after controlling for learning time. In the second experiment, providing an author generated drawing as a visual aid, did not appear to be more beneficial to the students' learning compared to having to create the drawing by themselves. The quality of the drawings was evaluated, and it was shown that higher quality drawings correlated positively with test performance. These findings support the idea that drawing whilst learning is an activity that encourages complex cognitive processing. Neither of the aforementioned studies on drawing and learning directly investigate whether similar results could be achieved by both copying a premade illustration and creating own illustrations, which poses a question whether it is the actual action of drawing itself that is beneficial, or if it is due to mental processes participating in creating own drawings.

While many neuroimaging studies have researched different types of creativity and creative tasks, few have contrasted creative tasks with mere copying of texts and images, and investigated how this might influence learning. The present study will investigate the interplay between human learning and the creative processes of making own descriptions and drawings, when compared to copying. There are many possible learning situations where one might face creative challenges, such as creating an illustration for a science paper, or portraying a historical event learnt through history classes in school. While one for example may feel tempted to verbatim copy the factual text or the illustration to a text about DNA, the previous research and theories outlined above suggest this may be less beneficial than non-verbatim writing the text

using your own words, or drawing the figure by yourself. Investigating differences in brain activity when either copying or creating own texts and drawings, can provide a new perspective on both learning and creativity.

The present study uses high-density EEG to examine brain oscillatory activity of adults when they by hand copy written descriptions using cursive writing, describe a given object or concept using cursive writing, copy provided drawings, and draw their own representations of a given object or concept. All participants use a digital pen and a PC with a touchscreen. The study sets out to examine differences related to creative processes when copying versus creating own texts and drawings, and whether these differences are connected to learning. It is assumed that drawing and describing can be considered to be more creative than copying, and that creating own drawings and descriptions may offer beneficial effects on learning and memory similar to that of non-verbatim encoding. Based on previous research on creativity, it was hypothesised that in the more creative conditions of drawing and describing, there would be more widespread oscillatory activity, especially in parietal and central areas, indicating an activation of larger neural networks. Furthermore, it was expected that the creative conditions would elicit synchronized alpha activity in frontal brain areas as typically seen in studies on creativity. Copying, on the other hand, was presumed to elicit primarily motor responses in sensorimotor areas, indicating a more automatic activity. The present study also wished to investigate if creativity could be seen as a process developing over time, or if it was more similar to a sudden flash of insight.

2 Procedure and methods

2.1 Participants

24 healthy, adult Norwegian participants (14 women, mean age 23.16 years, *SD* = 2) were recruited from the university campus (NTNU campus Dragvoll, Trondheim, Norway) and through word of mouth. Six participants (five women) were later excluded from the analyses due to noisy data. All participants completed the Norwegian version of the Edinburgh Handedness Inventory (Oldfield, 1971) before the experiment to determine their dominant hand. Only right-handed participants with a handedness quotient of > +0.6 took part. Each participant was awarded a 150 NOK cinema gift card after the experiment.

2.2 Experimental stimuli and paradigm

A Windows Surface Studio PC (Intel Core i7, 16 GB RAM) measuring 25.1" x 17.3" x 0.5" with a screen resolution of 4500 x 3000 (192 PPI) pixels, was used to display the target words and instructions to the participant. As the PC had a touchscreen feature, it functioned as a tablet where the participants used a digital pen to draw and write directly on the screen. On a separate Windows PC connected by internet cable to the touchscreen PC, the software E-prime 2.0 was used to generate 15 different Pictionary words of varying difficulty (e.g., concepts such as "house", to the more abstract "friendship"), 15 sentences, and 15 drawings. The participants were instructed to use the pen to either (a) *describe* the word on the screen by hand, using either full sentences or bullet points depending on their natural preference, (b) *draw* a picture representing the word on the screen without the use of any text or numbers, (c) *copy* by writing down a pre-made sentence, or (d) *copy* a premade drawing. Examples of a participant's work can be seen in Figure 1. The words, sentences, and drawings were presented in semi-randomised order on the screen, with the sentences and drawings in the (c) "copy text" and (d) "copy a drawing" conditions always appearing later than the similar words in the "draw" and "describe" conditions (e.g. "Draw: King" would always precede the task to copy a premade drawing of a king). Each task started with the instruction (i.e., "draw", "describe", "copy text" or "copy a drawing") appearing 1-2 seconds before the word/sentence/drawing showed up, and the participants were given 25 seconds to do each task before a low beeping sound signaled time was up and the screen subsequently emptied. All premade sentences were presented in a sans

serif font, and the premade drawings were in black and white and created with a digital pen similar to that used in the experiment. The premade drawings and sentences showed up in the upper left part of the screen, whereas the instructions to either draw or describe the accompanying word (e.g. "Draw: Fiddle") showed up in the upper center part of the screen. Drawings and text produced by the participants were stored on the touchscreen PC for offline analyses.
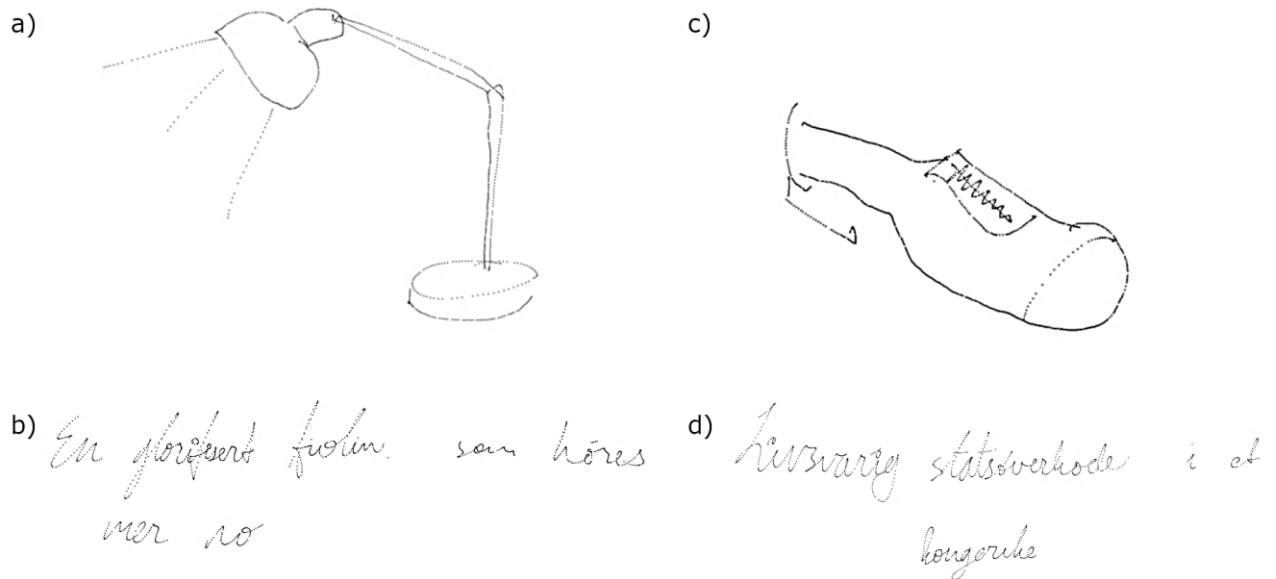

Figure 1: *Examples of the work of a male participant when (a) drawing a lamp, (b) describing a fiddle, (c) copying a drawing of a shoe, and (d) copying a descriptive text about a king.*

2.3 EEG data acquisition

Using a Geodesic Sensor Net (GSN) 200 (Tucker, 1993), electroencephalography (EEG) activity was recorded. Each adult-sized net comes in various sizes, all containing an array of 256 sensors evenly distributed across the scalp. To achieve optimal signal-to-noise ratio (Picton, Bentin, Berg, Donchin, Hillyard, Johnson, Miller, Ritter, Ruchkin, Rugg, & Taylor, 2000), an EGI amplifier was used to amplify signals at a maximum impedance of 50 kΩ. The EEG signals were recorded by a separate Macintosh computer at a sampling rate of 500 Hz and were later stored for off-line analyses.

2.4 Procedure

At arrival, the participants were given verbal information about the experiment and asked to sign a consent form, after which they completed the Edinburgh Handedness Inventory

(Oldfield, 1971). To ensure the EEG net would be a good fit, the participant's head circumference was measured, and the correctly sized net was soaked in a saline electrolyte solution for at least 10 minutes to ensure optimal electrical conductivity. While the net was soaking, the participant was given further instructions about the experiment in the experimental room. Before the net was mounted on the head of the participant, the net was lightly patted dry with a towel.

Figure 2: *A participant seated in front of the touchscreen PC during the experiment.*

The participant was led into the experimental room and sat down in a comfortable, adjustable chair facing a computer tablet. The tablet was placed on a table which was moved as close to the participant as possible, and the angle of the tablet was adjusted according to the height and comfort of the participant. Figure 2 shows how a typical participant during the experiment was seated in front of the touchscreen PC. To minimize movement artifacts from the hand and arm, the participants were asked to rest their elbow on the table in front of them while using the pen to draw and write, and also to attempt to write in cursive. If needed, the chair was raised or lowered to ensure the participant was comfortable. The net was attached to the amplifier, and the impedance was checked in the adjoining control room containing the data acquisition computers. If the contact between the net and scalp was poor, the bad electrodes were improved by adding more saline electrolyte solution using a disposable pipette, and the net was adjusted to ensure a tighter fit. The experiment was carried out under good lighting conditions.

Each participant was given a pre-test before the experiment with an assistant present. The participants were allowed to ask questions if needed during the pre-test. The pre-test contained one example of each type of task, using a word which did not appear in the actual experiment. After the pre-test was completed, any small adjustments to sitting position were made before the assistant left the room and the experiment started. Two experiments were conducted at the same time, where a total of 90 trials (6 conditions) were presented to the participant; however, the focus of this paper was the conditions "*draw*", "*describe*", "*copy text*" and "*copy a drawing*" (15 trials per condition, 60 trials in total). The first 5 seconds of data were recorded for each trial. The participants were asked to prepare themselves for the next task when they noticed the instruction text showing up on screen, and attempt to move as little as

possible while doing the task, especially for the first few seconds, in order to minimize movement artifacts. The experiment, including the extra experimental conditions not included in this paper, lasted approximately 45 minutes. Each participant was given a short break 25 minutes into the experiment, and if they needed additional breaks, they were instructed to knock on the window to the control room, and the experiment would be paused.

2.5   Analysis

The EEG recordings were segmented with the software Net Station and exported, before the data were analyzed using Brain Electrical Source Analysis (BESA) research software (version 6.1). The averaging epoch ranged from -250 to 4500 ms at a baseline definition of -250 to 0 ms. To avoid line interference in the data, the notch filter was set at 50 Hz. A low cut-off filter was set at 1.6 Hz to remove slow drift in the data, and the high cut-off was set at 75 Hz. To avoid bad channels caused by head or body movements from contaminating the data, the channels either were removed completely or went through signal estimation through spherical spline interpolation (Picton et al., 2000). Six participants (five women) were excluded from the study due to their data containing more than 10 % bad channels. Artifacts typically caused by eye blinking or movements were manually corrected by applying spatial filters to separate brain activity from noise. While scanning the data for artifacts, threshold values were set for gradient and low signal at 75 and 0.1 µV respectively, and amplitude was set at 200 µV. The mean number of accepted trials for the participants in the four conditions *describe, draw, copy text* and *copy a drawing* was 53 (*SD* = 4), more or less equally divided over the four experimental conditions.

2.6   Frequency analysis

EEG studies in the time-frequency domain of the natural frequencies of the brain provide the opportunity to investigate a combination of sensory and cognitive functions (Başar, Başar-Eroğlu, Karakaş, & Schürmann, 2000). Brain oscillatory activity in the EEG can be categorized as evoked or induced activity. Evoked activity, the signal of interest, is time- and phase-locked to the stimulus while the ongoing EEG acts as additive noise, and averaging techniques can be used to enhance the signal-to-noise ratio. Induced activity, on the other hand, is time- but not phase- locked, and may be detected by frequency analysis as it cannot be extracted by averaging (Pfurtscheller and Lopes da Silva, 1999). Evoked and induced activity represent frequency specific changes of the ongoing EEG, and may consist of either increases

or decreases of power in a frequency band, referring to changes in the synchrony of underlying neuronal populations.

Time-frequency analyses were carried out using multiple source dipoles modeling the brain areas of interest (Figure 3). Measuring oscillatory activity on the electrodes placed on the surface of the scalp can be problematic, as waveforms on the scalp have mixed brain source contributions due to the wide distribution of focal brain activity on the scalp surface; this is due to the nature of dipole fields and the smearing effect of volume conduction in EEG. To ensure an optimal separation of brain activity, a source montage, which separates the different brain activities derived from a multiple source model, was used. The sources cover temporal, frontal, parietal, central and occipital areas; areas which have been linked to the processing of sensory-motor actions relevant to the present study (Van der Meer & van der Weel, 2017). A 4-shell ellipsoidal head model (Berg & Scherg, 1994; Hoechstetter, Bornfleth, Weckesser, Ille, Berg, & Scherg, 2004) was created, with the artifact-corrected coordinate files attached, for each participant to transform the data from electrode to source dipole level. The time-frequency displays represent the induced changes in oscillatory activity over time, and the frequencies are normalized to the baseline of each frequency (temporal spectral evolution, TSE). Average evoked response signals were subtracted before a TSE was computed to focus solely on the induced brain activity. The frequency and time sampling were set at 1 Hz and 50 ms respectively, while the low frequency cut-off was set at 2 Hz, and the high frequency cut-off at 60 Hz.
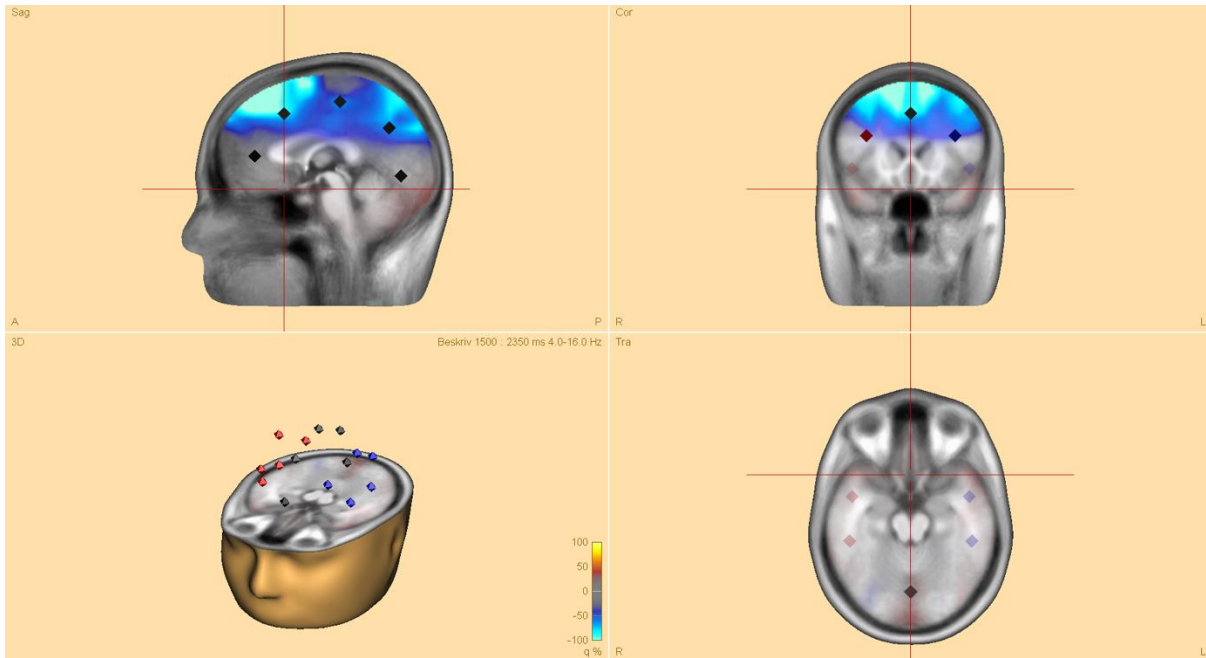
Figure 3: *Head model of a typical male participant showing the source dipoles (location and direction of electrical current) modelling the brain areas of interest over temporal, frontal, parietal, central and occipital areas. Blue areas indicate event-related desynchronization (ERD).*

To test for significance in amplitude and frequency ranges, BESA Statistics 2.0 was used. Using this program, it was possible to compute the average of the TSE data for all the participants to investigate the significant oscillatory activity in the individual TSEs.

Two two-tailed t-tests were run comparing *draw* with *copy a drawing*, and *describe* with *copy text*. Cluster alpha denotes the significance level for making clusters in time/frequency, and was set at 0.05, while the number of permutations was set at 10000. High- and low cut-offs for frequency were kept at 60 and 2 Hz, respectively, and epochs set from -250 to 4500 ms.

3 Results

3.1 Time-frequency results

Time-frequency maps and time-frequency probability maps of the brain areas of interest in a typical participant are shown in Figure 4 and Figure 5, respectively, across the four experimental conditions: describe, copy text, draw, and copy a drawing in the frequencies 2-60 Hz (displaying oscillatory activity in delta 2-4 Hz, theta 5-8 Hz, alpha 9-12 Hz, beta 13-30Hz, and gamma > 30 Hz bands). The selected brain regions are in frontal, central, parietal, temporal, and occipital areas of the brain. The maps represent the amplitude of the oscillations, i.e. the estimated neural activity in the chosen areas during each task epoch (0 to 4500 ms) when compared to baseline (-250 to 0 ms) activity. The blue and red colours represent event-related synchronization (ERS) and event-related desynchronization (ERD), respectively, referring to increased or decreased spectral amplitude. The TSE maps show widespread ERD in all the conditions, albeit to a lesser degree when copying a drawing and copying text where more synchronized low-frequency activity in the theta/alpha band is seen. ERD, starting right after baseline and lasting throughout the recorded time, in parietal areas in the alpha band is more apparent when drawing and describing compared to copying a drawing and copying text. This parietal alpha ERD is paired with concurrent gamma band ERS in the 30 to 60 Hz range for the draw and describe conditions, starting at approximately 500ms after baseline and lasting to the end of the recorded time. While parietal alpha ERD and gamma ERS occur when copying a drawing, these oscillatory frequencies do not occur simultaneously. Beta band activity around 20 Hz is evident in all conditions in the central areas, particularly when copying a drawing. Overall, most of the activity when drawing and describing starts at about 500 ms and lasts until the end of the recorded time, without any major changes in synchronization nor amplitude.

The time-frequency probability maps show that drawing elicited more widespread oscillations overall in terms of frequency ranges and brain sources compared to copying a drawing, and describing elicited more widespread oscillatory activity than copying text.
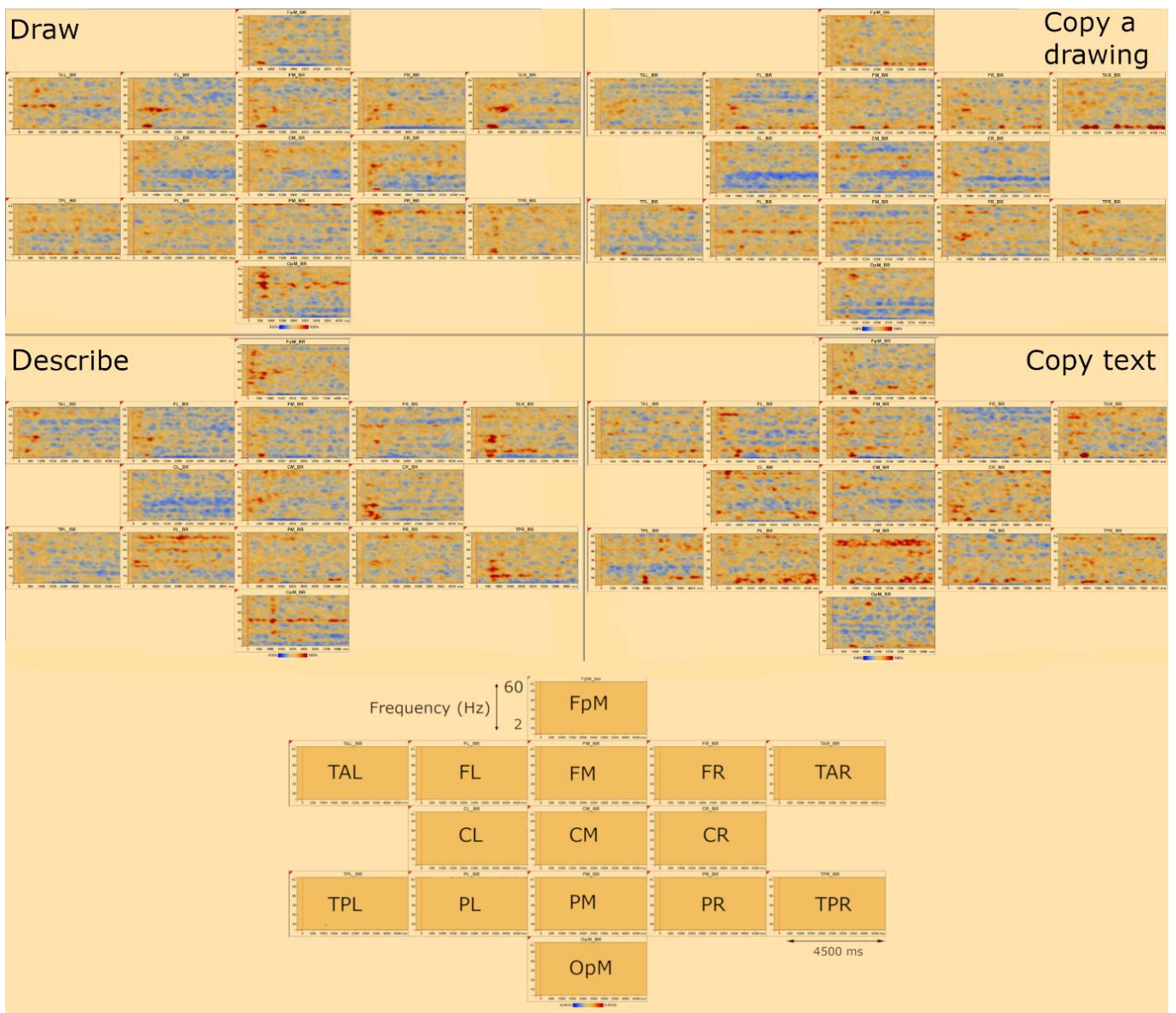
Figure 4: *Time-frequency maps of a typical female participant with the selected brain regions in frontal, central, parietal, temporal, and occipital areas. The y-axes show the amplitude (signal magnitude), in frequencies ranging from 2 to 60 Hz, which represent estimated neural activity across the brain regions compared to baseline (-250 to 0 ms) in the conditions draw, copy a drawing, describe, and copy text. Baseline activity and 4500 ms recording time is shown on the x-axes, with trial onset indicated by a red line. Red areas indicate synchronization (ERS), whereas blue areas indicate desynchronization (ERD) of the brain activity.*

FpM, fronto-polar midline; FL, frontal left; FM, frontal midline; FR, frontal right; CL, central left; CM, central midline; CR, central right; TAL, temporal anterior left; TAR, temporal anterior right; TPL, temporal posterior left; TPR, temporal posterior right; PL, parietal left; PM, parietal midline; PR, parietal right; OpM, occipito-parietal midline.
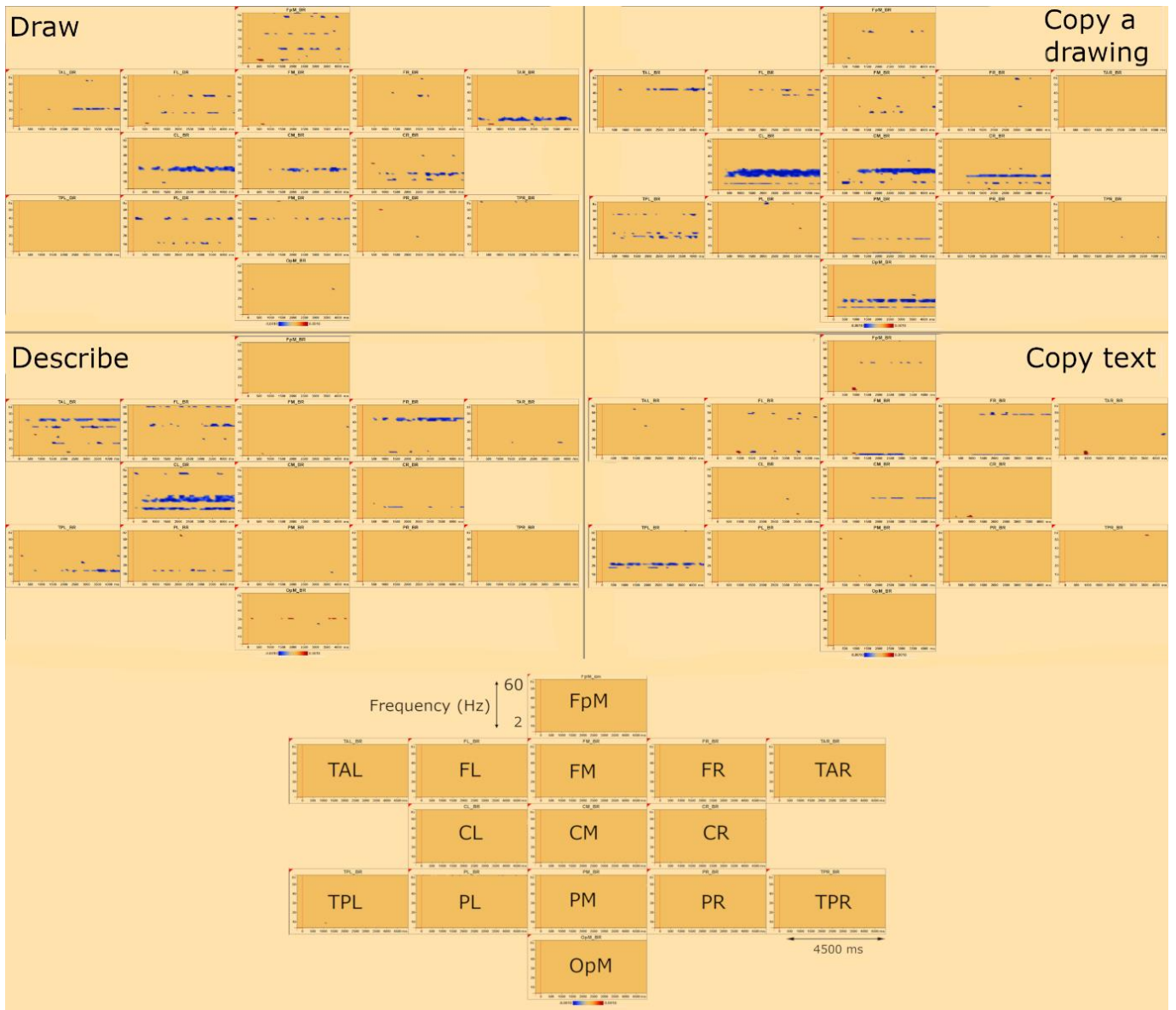
Figure 5: *Time-frequency probability maps of the same typical female participant as in figure 4, showing the selected brain regions in frontal, central, parietal, temporal, and occipital areas. The y-axes display the probabilities (p < 0.05) of the estimated neural activity in the frequencies 2 to 60 Hz. The probabilities of the estimated neural activity are compared to baseline (-250 to 0 ms) in the four conditions draw, copy a drawing, describe, and copy text. The x-axes show the baseline activity and 4500 ms recording time. Stimulus onset is indicated by a red line. The red areas indicate synchronization (ERS), and the blue areas represent desynchronization (ERD).*

Figure 6 shows averaged time-frequency maps of all the participants across the four experimental conditions, in five sources of interest related to creativity and learning processes: frontal right (FR), frontal left (FL), central medial (CM), parietal medial (PM), and parietal left (PL). Theta (4-7 Hz) ERS lasting from 500 ms to the end of the trial is evident in central and

parietal regions when describing and copying text, whereas this theta ERS is seen as bursts in the parietal regions when drawing and copying a drawing. The frontal regions show widespread ERD across the higher (beta 13-30 Hz; gamma 30 ≥ Hz) frequency bands, particularly when copying text and copying a drawing, starting at approximately 500 ms (1000 ms when copying text) and lasting throughout the recorded time, while the frontal ERD when drawing shifts to ERS at about 1000 ms before shifting back to ERD at around 2000 ms. Frontal high-frequency ERD can also be found when describing, albeit starting later at about 2000 ms, and is preceded by bursts of ERS at around 1000-1500 ms. For drawing and copy a drawing, consistent beta band ERD at around 20 Hz is evident in the central regions. In PM, alpha (8-12 Hz) ERD is found when drawing, seen as small ERD bursts when describing, and as ERS when copying text. In general, the draw and copy a drawing conditions show more prominent ERD across the sources, including those not shown here. Additionally, the describe and copy text conditions show more ERS across the brain sources (in higher frequencies for describe, versus lower frequencies for copy text).
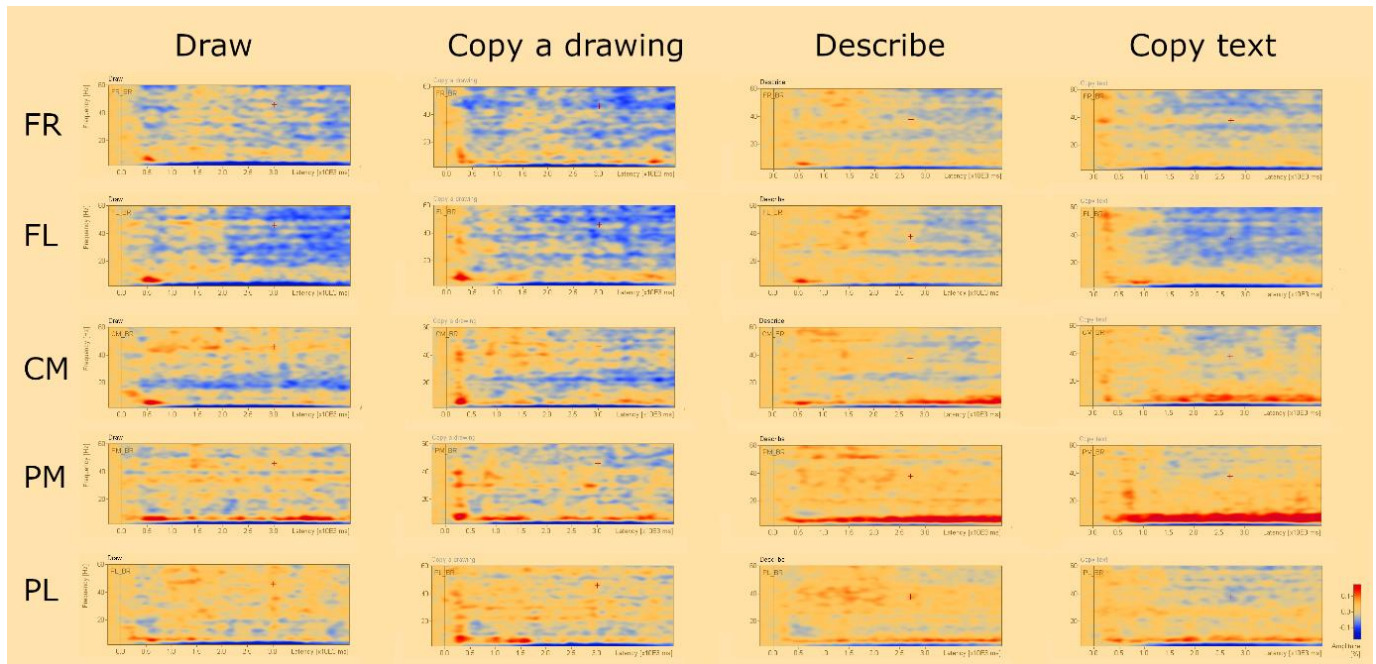

Figure 6: *Time-frequency maps averaged across all (N = 18) participants, in the sources frontal right (FR), frontal left (FL), central medial (CM), parietal medial (PM), and parietal left (PL). The y-axes display the estimated neural activity (amplitude %) in frequencies ranging from 2 to 60 Hz. The x-axes display baseline activity (-250 to 0 ms) and post-stimulus (indicated by a vertical line) activity (0 to 4500 ms). The red areas represent synchronization (ERS), while the blue areas represent desynchronization (ERD). The gradient in the bottom right corner represents amplitude (in %), where a more saturated colour translates to higher amplitudes.*

3.2 T-test analyses

Two separate t-tests were run to compare drawing versus copying a drawing, and describing versus copying text. Figure 7 displays the significant clusters alongside the time-frequency maps of the conditions in the source. Significant ($p < 0.05$) differences in the gamma band were found in the central right (CR) area between drawing and copying a drawing, and is seen as gamma ERD when copying a drawing. Additionally, significant ($p < 0.05$) differences between describing and copying text was found in the parietal left (PL) are in the gamma band, where this activity was seen as ERD when copying text. See Table 1 for details about the significant clusters.
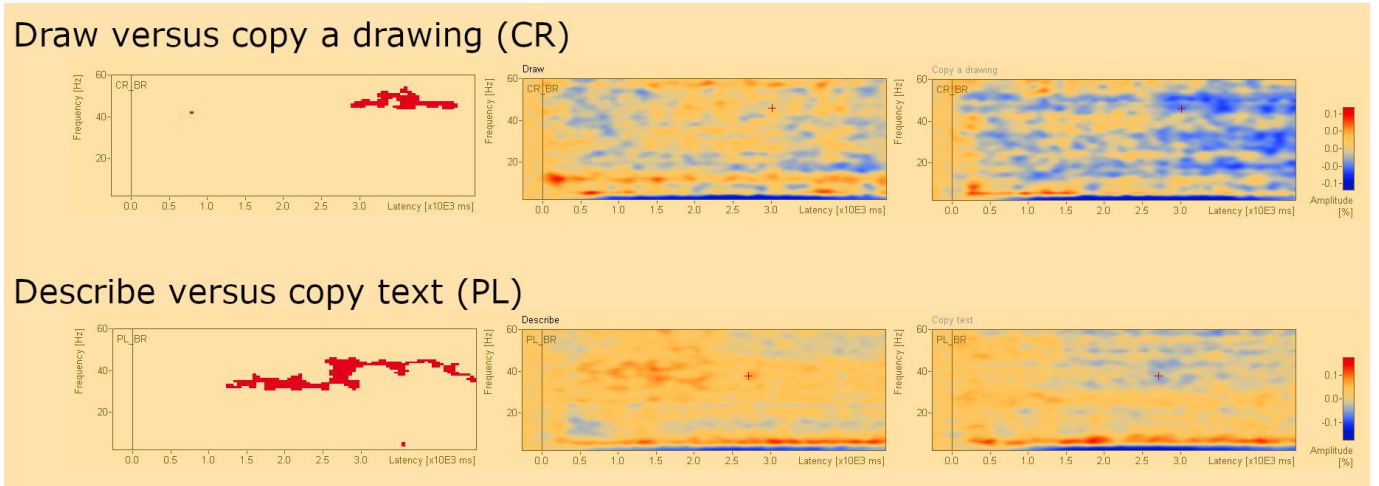

Figure 7: *Displays of significant results when doing a t-test comparison between the conditions draw (top middle) versus copy a drawing (top right), and describe (bottom middle) versus copy text (bottom right). The significant clusters are displayed to the left. The significant cluster when comparing the drawing and the copy a drawing conditions were in the central right (CR) source, in the gamma (specifically 44-54 Hz) band from 2900 to 4250 ms, whereas the significant cluster when comparing the describe and copy text conditions were in the parietal left (PL) source, in the gamma (specifically 31-46 Hz) band from 1250 to 4500 ms. The gradients to the right show amplitude (in %), where a more saturated colour represent higher amplitudes.*

Table 1: Permutation test results for the significant clusters in the two separate t-tests

Cluster ID	p-value	Mean for draw	Mean for copy a drawing	Start time	End time	Start frequency	End frequency
CR	0.040	-0.01	-0.19	2900	4250	44	54
Cluster ID	p-value	Mean for describe	Mean for copy text	Start time	End time	Start frequency	End frequency
PL	0.035	0.09	-0.12	1250	4500	31	46

4 Discussion

This study set out to investigate differences in creativity during copying and the creation of own texts and drawings, and how these different tasks may be related to learning and memory processes in adults using EEG. The participants were tasked with creating drawings and descriptive texts on given words, as well as copying provided drawings and written descriptions. It was hypothesized that the participants' brain electrical activity when creating own drawings and descriptions would be more connected to creative processes than mere copying, and that this type of creativity could be linked to learning processes.

Widespread oscillations across multiple brain sources and frequency bands were more evident when drawing and describing compared to copying, particularly in the lower-frequency bands delta, alpha and beta. Widespread low-frequency ERD has been proposed to be the result of the involvement of larger neural networks and enhanced information processing beneficial to learning processes (Pfurtscheller & Lopes da Silva, 1999; van der Meer & van der Weel, 2017). The widespread oscillatory observed when the participants were drawing and describing in the present study thus indicates that there are larger neural networks involved in these tasks compared to copying text and copying a drawing. Widespread oscillations have also been connected to creativity, where Boot, Baas, Mühlfield, de Dreu, and van Gaal (2017) argued that creativity is a result of the interplay between various cognitive processes likely involving a large-scale neural network. This is supported by neuroimaging studies that have associated creativity with several different brain areas (Dietrich & Kanso, 2010; Kowatari et al., 2009; Pidgeon et al., 2016; see meta-analysis by Boccia, Piccardi, Palermo, Nori, & Palmiero, 2016). As drawing and describing compared to copying a drawing and copying text were presumed to be more creative, the finding of more widespread oscillations in these tasks supports the notion of creativity as a process that engages multiple neural networks. The widespread activity seen in this study also challenges the old view that creativity is a component of the right hemisphere (Dietrich, 2019b).

The results of the present study show significant differences between drawing and copying a drawing, as well as between describing and copying text, seen as gamma ERD in the central right (CR) source in the parietal left (PL) source, respectively. Gamma oscillations are believed to be central to attentional top-down attentional processing (Debener, Herrmann,

Kranczioch, Gembris, & Engel, 2003), communication between cortical regions (Gregoriou, Gotts, Zhou, & Desimone, 2009; Jensen & Mazaheri, 2010), feature binding of perceptual stimuli (Engel & Singer, 2001; Gray & Singer, 1989; Gregoriou et al., 2009), and are related to multiple cognitive functions in a variety of brain regions and even different species (Başar, Başar-Eroğlu, Karakaş, & Schürmann, 1998; Fries, Nikolic, & Singer, 2007; Fries, 2009; Goddard, Sridharan, Huguenard, & Knudsen, 2012). While most of the research on gamma oscillations focuses on synchronized gamma, desynchronized gamma activity has been linked to a reduction of processing in underlying cortical regions (Jensen & Mazaheri, 2010), and an active decoupling of neural assemblies that is required to move from one cognitive state to another (Rodriguez, George, Lachaux, Martinerie, Renault, & Varela, 1999; Fell, Fernández, Klaver, Elger, & Fries, 2003). Gamma ERD in sensorimotor areas has also been connected to planning and the execution of bodily movement, especially when paired with beta ERD (Iijima, Mase, Osawa, Shimizu, & Uchiyama, 2015; Wagner, Solis-Escalante, Scherer, Neuper, & Müller-Putz, 2014), as beta ERD has been connected to voluntary movement (Engel & Fries, 2010; Iijima et al., 2015; Palmer, Zapparoli, & Kilner, 2016; Pfurtscheller & Lopes da Silva, 1999). As found in the present study, gamma ERD is particularly prevalent when copying a drawing and copying text in sensorimotor areas, and this gamma ERD coincided with beta ERD at around 20 Hz. Taken together, this indicates that the significant differences in gamma ERD in the sensorimotor areas CR and PL when copying versus drawing and describing, may reflect motor responses.

Gamma ERD was also observed in the frontal areas, and the prefrontal cortex is associated with for instance planning and working memory (Miller, Lundqvist, & Bastos, 2018; Purves et al., 2004). As high-frequency oscillations in frontal sources in EEG research are likely to be contaminated by eye movement (Berg & Scherg, 1991; Picton et al., 2000), it is possible that the frontal gamma ERD found particularly in the copying conditions is dominated by ocular movements as the participant was looking back and forth between the text or drawing they were copying, and their own rendition of it. The observed gamma ERD may however also indicate cortical inhibition. A study on mental calculation found gamma ERD in the prefrontal cortex paired with gamma ERS in the parietal lobe, where it was suggested that the gamma desynchronization may be interrupting neural activity that could interfere with the ongoing task (Ishii, Canuet, Ishihara, Aoki, Ikeda, Hata, Katsimichas, Gunji, Takahashi, Nakahachi, Iwase, & Takeda, 2014). Put differently, tasks demanding attention require activation of some brain regions, and deactivation of others that are deemed irrelevant. In the study by Ishii et al. (2014),

the authors proposed that the desynchronized prefrontal cortex had a supportive rather than active role in the mental calculation tasks, where it was managing parallel neural processes that otherwise would have interfered with the task at hand. While the contribution of frontal gamma ERD on the present study is unclear, the observed frontal gamma ERD when copying may indicate less neural communication with the prefrontal cortex.

Similar to van der Meer and van der Weel (2017), gamma ERS was found within the first 2 seconds of the trial in the present study when the participants were drawing and describing, before this oscillatory activity changed to ERD. While there is no set limit for the conception of an idea, previous research (Benedek et al., 2014; Jung-Beeman et al., 2004) supports the suggestion that the first seconds of the creative tasks can be considered the ideation phase. While the meaning of gamma oscillations in creativity research is not clear due to the wide variety of reported results in this frequency band (Dietrich & Kanso, 2010), an increase of synchronized gamma in the creative conditions was suggested by Nagornova (2007) to be caused by creative activity. Furthermore, synchronized gamma has been observed in studies on artists versus non-artists, where more gamma and high-beta synchronization was suggested to reflect enhanced binding ability of perceptual stimuli in artists (Bhattacharya & Petsche, 2002). While gamma perceptual binding often is connected to the bottom-up integration of the features (for example visual or auditory) of external objects, it also allows binding in a top-down manner (for example features of the mental representation of a car) (Tallon-Baudry & Bertrand, 1999). As the observed gamma ERS in the present study occurs in the ideation phase, this may suggest binding of features of object representations in memory of the given word. This synchronization during the first seconds may thus reflect retrieval of long-term memory during the ideation phase when the participant was trying to think of how best to draw or describe the given concept. The previously outlined study on creative writing by Shah et al. (2013), found activation in areas associated with memory and semantic integration, and other studies on creativity using different experimental methods have found memory to be an important component of creativity (Dietrich, 2004; see Boccia et al., 2015 for a review). For example, in a study on generating ideas, Benedek et al. (2014) found activation in the medial temporal lobe (MTL), left inferior frontal gyrus (IFG), and superior frontal gyrus (SFG); brain areas related to memory retrieval and semantic integration. When investigating divergent thinking, the authors found that both divergent and convergent idea generation are dominated initially by memory retrieval, whereas the divergent ideas typically occurred at a later stage after a retrieval of the more accessible, common ideas. The authors argue that the creation of novel creativity

develops over time, and this argument is supported by other studies (Beaty & Solvia, 2012; Gilhooly, Fioratou, Anthony, & Wynn, 2007; Schwab, Benedek, Papousek, Weiss & Fink, 2014). The idea that creativity develops over time rather than appearing suddenly with a defined start and end, supports Withagen and van der Kamp's (2018) ecological view on creativity. In their view, creativity unfolds over time as the artist is in contact with the object or task at hand. In the present study, the participants initially thought of how to best describe or draw the given object or concept before executing the task. Their creative process of making their own descriptions or drawings was governed not only by the words provided, but also by the tools at hand and the limited time. It is very likely the final work would be different if the participants had other options, like the ability to colour the drawings or erase lines. The creative idea had to be adapted in contact with the external factors, like how a sculptor would adapt their idea to the material they had to work with, as well as to how the result gradually was turning out. If the sculptor was to accidentally chop the arm off a marble sculpture in making, she would have to adapt her initial idea to the current state of the sculpture. The work continuously changes as it is being worked on, and it is therefore difficult, if not impossible, to say when the brain stops being creative and when it's merely executing motor commands.

A shift from synchronized to desynchronized gamma has been linked to successful formation of memories (Fell, Klaver, Lehnertz, Grunwald, Schaller, Elger, & Fernández, 2001), and this shift is in the present study paired with theta ERS in frontal and central sources particularly when the participants were describing and drawing. Recent research has connected the pairing of theta and gamma synchronization to long-term memory formation and learning, where the fast oscillatory gamma activity supports long-term potentiation in the hippocampus by synchronization of pre- and postsynaptic activity, and the slower theta rhythm evokes long-term potentiation or long-term depression depending on whether the presynaptic action potential arrives during a period of theta synchronization or desynchronization (Axmacher, Mormann, Fernández, Elger, & Fell, 2006; Engel & Singer, 2001; Jensen, Kaiser & Lachaux, 2007). Building on this, studies have found that the strength of theta-gamma coupling appear to increase during learning (Kendrick, Zhan, Fischer, Nicol, Zhang, & Feng, 2011; Tort, Komorowski, Manns, Kopell, & Eichenbaum, 2009). These findings support the hypothesis that drawing own pictures and describing own texts puts the brain in a state that is more beneficial to memory formation and learning than mere copying does.

In addition to playing a part in memory processes, theta band oscillations are believed to be involved in sensorimotor integration (Bland & Oddie, 2001), and theta oscillatory activity

was particularly evident in the present study in sensorimotor sources. Sensorimotor integration refers to the ability of processing, organizing and transforming sensory information to appropriate motor responses (Melnik, Hairston, Ferris & König, 2017; Velasques, Cagy, Piedade, & Ribeiro, 2013), and has been suggested to be beneficial to learning processes as movement contributes to the stimulation of more parts of the brain (Makino, Hwang, Hendrick, & Komiyama, 2016; Melnik et al., 2017; van der Meer & van der Weel, 2017). In addition to the aforementioned suggested relation to creativity and memory, it is possible that the shift from gamma ERS to ERD coinciding with theta ERS in the present experiment also reflect the sensorimotor integrative process, representing a transition from higher cognitive processes to a subsequent motor response. Sensorimotor integration is suggested to be a vital part of the creative, practical (as opposed to purely mental) process, as the perception of the task and potential tools need to be processed correctly to be able to find the suitable motor responses to execute the idea as planned.

Alpha ERD combined with theta ERS was observed in parietal sources to a larger extent when the participants were drawing and describing compared to copying, and the coupling of these oscillations are believed to be important to learning and memory processes, with theta synchronization associated with working memory processes and the ability to encode new information, and alpha desynchronization associated with attention and semantic long-term memory performance and retrieval (Jensen & Lisman, 2005; Klimesch, 1999; Klimesch, Schack, Schabus, Doppelmayr, Gruber, & Sauseng, 2004; Klimesch et al., 2011). Theta increases are positively correlated with increases in working memory load (Cashdollar, Malecki, Rugg-Gunn, Duncan, Lavie, & Duzel, 2009; Jensen & Tesche, 2002; Klimesch, 1999), and this increase has been observed in parietal areas during language tasks where the amplitude increased as a sentence unfolded (Bastiaansen, Magyari, & Hagoort, 2010), supporting the finding in the present study of increases of theta ERS in parietal areas when the participants were writing.

While the aforementioned research on creativity, and divergent thinking in particular, has found synchronized alpha activity in frontal and parietal areas during creative tasks, these findings were not replicated here. Alpha ERS as seen in divergent thinking tasks, which are characterized by finding untraditional solutions or ideas, has been linked to cortical inhibition and gating information to other, more relevant brain areas (Jensen & Mazaheri, 2010; Pfurtscheller & Lopes da Silva, 1999). Creativity has previously been linked to defocused cognitive states marked by cortical inhibition, such as mind wandering (Fox & Beaty, 2019),

and drug intoxication (Jung, Mead, Carrasco, & Flores, 2013). Alpha ERD can be interpreted as a functional correlate of cortical activation, as it is thought to reflect increased excitability levels of neurons in the brain areas where the alpha ERD is observed; this may be a source of improved information transfer in thalamo-cortical circuits that relates to access to long-term memory (Klimesch, 1997; Pfurtscheller & Lopes da Silva, 1999). Put differently, alpha ERD is seen in cortically engaged regions, compared to alpha ERS in disengaged regions (Jensen & Mazaheri, 2010). ERD in the alpha band has been linked to increased task complexity, and increased attention, effort, and performance (Dujardin, Derambure, Defebvre, Bourriez, Jacquesson, & Guieu, 1993; Klimesch, 2012; Pfurtscheller & Lopes da Silva, 1999), which suggests that the experimental conditions in the present study demanded focused attention from the participants. While synchronized alpha has been a common finding in studies on creativity, desynchronized alpha in creative visual tasks has also been reported. The alpha desynchronization was attributed to the visual aspect of the creative task (Volf, Tarasova, Razumnikova, 2010), for example during mental imagery (Bhattcharya & Petsche, 2002; Bhattcharya & Petsche, 2005) and in parietal and occipital areas during idea generation in a visual completion task (Rominger, Papousek, Perchtold, Weber, Weiss, & Fink, 2018). It is possible that the alpha ERD was elicited during mental visualization of the given word, meaning that a participant asked to describe or draw a lamp, mentally visualized the object. The observed alpha ERD when drawing and describing can also indicate that it is connected to focused attention and a high degree of effort as the task was considered more complex than mere copying. While the drawings and texts the participants were asked to copy differed in difficulty, it is presumed on basis of the observed sensorimotor gamma and beta ERD that copying was a more automatic motor process that did not require the recruitment of higher cognitive processes. When asked to draw or describe the given words themselves, more and higher cognitive processes were initiated. Contrary to a significant amount of creativity research, they were not asked to merely mentalize the answer (e.g. think how they would draw a lamp), but also to practically execute the task. Thus their drawings and descriptions not only recruited higher cognitive processes in coming up with the idea, but also they required focus, planning and motor responses. Creativity is thus proposed to be embedded in other cognitive processes, representing a more realistic model of how creativity unfolds in a real-life setting where a practical task must be solved**.**

The conditions in the present experiment did not require unfocused attention to connect distant concepts together, but rather demanded a practical solution of creating mental models

and subsequently producing it using the digital pen and touchscreen PC. It is likely many participants, possibly due to a combination of time constraints and not being required to produce as original and novel drawings and descriptions as possible, did not spend much time searching their memory for different mental representations of the given concept, but rather went with their initial idea. Additionally, the participants would have to adapt their idea to be sufficiently practical to be able to draw or describe it in the limited time provided. The word "birthday", for example, might elicit mental representations of a big, colourful event filled with people, gifts and a lot of things happening, but the limited time and tools available could necessitate the selection of only a few elements that the participant considered fundamental, or even stereotypical, to the representation of "birthday" (e.g. someone blowing out the lights on a big cake). Thus, building on the present study, future research could investigate differences in creativity further by adding another condition where the participants would be asked to draw or describe the concept as uniquely as possible, and see whether this new task would elicit different oscillatory responses (and different drawings/descriptions) than those observed here. Future studies could also make use of a small jury to judge which of the finished drawings and descriptions would be considered more creative. Nevertheless, it can be argued that the types of creativity seen in tasks eliciting alpha synchronization versus desynchronization are merely different, rather than one necessarily being better or more creative than the other. This supports Dietrich's (2019a) argument of the existence of different types of creativity, and that these types are accompanied by different types of brain activity. For example, an author might come up with a brilliant idea for a novel while in the shower, whereas he might also come up with an equally brilliant idea while consciously thinking of ideas in front of his typewriter. The bright idea coming seemingly out of nowhere might indicate his brain being in a defocused state, i.e., dominated by alpha synchronization. On the other hand, the idea conceived during focused brainstorming and deliberation might signal alpha desynchronization, as he is hard at work, focused on the task at hand and wants to avoid irrelevant thoughts from interrupting. However, rather than completely separating these types of creativity, it is possible that they interact with each other in the long term: No matter how the initial idea came to mind, it will likely be elaborated upon, and new ideas based on the original idea can start to appear like an unfolding chain of events. Put differently, creativity can come in many forms, and people can exhibit creativity in different ways.

In addition to the studies on drawing and memory outlined in the introduction of this paper, there may be long-term benefits to the brain by engaging in creative tasks, as studies

have shown that artistic training may lead to functional and structural changes in the brain. Chamberlain, McManus, Brunswich, Rankin, Riley and Kanai (2013) found observational drawing ability to be related to increases in grey matter density in the left anterior cerebellum and right medial frontal gyrus, as well as an increase in grey matter density in the right precuneus in art students. These areas are linked to integrating external (e.g. visual stimuli) and internal states (e.g. memory) with action, and mental imagery. The authors suggested that observational drawing ability were related to procedural memory that help the artist deconstruct visual scenes, and brain structures related to fine motor control. Similar findings were observed by Zhu, Chen, Tang, Cao, Hou and Qiu (2015) who found a positive correlation between creative activities and grey matter volume in the premotor cortex, which is a structure associated with creating and planning motor responses. As grey matter is a vital part of the brain that decreases with age (Purves et al., 2004), the potential development of these areas with artistic training is a strong argument for implementing more creative courses in schools. Although the research thus far only has found indications of short-term effects, longitudinal studies could investigate whether these changes were indeed permanent. For practical use of the knowledge provided by the present study, it is suggested to implement creative tasks during learning situations. While it is not argued that all creative effort leads to enhanced learning, there has been found overlap in creative and cognitive learning processes, and the research on changes in brain structures is promising.

As there appears to be potential learning benefits to creating own drawings and text over copying, future studies could examine further how much information is retained when one is creating own versus copying texts and images, both in terms of factual and conceptual recall. As previously suggested by van der Meer and van der Weel (2017), handwriting and drawing are assumed to be more beneficial to learning than typing, and the findings in this study suggests students in learning situations could benefit from including more creative practises. It is proposed that students and others may be doing themselves a disservice by copying texts and images instead of spending some extra time putting together their own. Investigation of the potential benefits of crafting one's own texts and images by hand is especially pertinent as a new generation is growing up with less time devoted to using pen and paper in lieu of the computer in schools. It is however not suggested to attempt to rid computers from schools and other learning arenas, but rather encourage to bridge the gap between new and old technologies by for example taking advantage of tablets and computers with touchscreens.

4.1 Conclusion

The present study found connections between creativity and learning in adults' oscillatory activity, where participants making own drawings and descriptions elicited oscillations linked to higher cognitive processes such as memory and learning processes, whereas copying premade drawings and copying texts were more automatic, dominated by motor responses as suggested by beta and gamma ERD in sensorimotor areas. There was found widespread oscillatory activity particularly when drawing and describing, suggesting the activation of larger neural networks that put the brain in a state for learning. Furthermore, gamma ERS was found in the ideation phase of making drawing and descriptions, and this oscillatory activity was linked to memory retrieval, sensorimotor integration and perceptual binding of object representations in memory when trying to figure out how to best describe to draw the given word. It was suggested that creativity develop over time, as opposed to the creativity process being marked by a definite start and end. In creative tasks like making own drawings and descriptions, an activation of memory seems important to create a mental representation of the given concept, before the actual idea might need to be adapted to real world constraints, such as time limitations and available materials. Surprisingly, the results from the present study revealed alpha ERD when drawing and describing, which indicate that these tasks necessitated focus and attention, and that irrelevant thoughts were prevented from interfering with the thought process. Creativity may encompass many mental states, whether defocused and marked by inhibition of the frontal lobe, or deliberate and attentive to the task at hand. Future research could investigate creativity further by introducing another experimental condition where the participants should attempt to create as creative and unique renditions of the given concept as possible. While there may still be a lot we do not know about creativity and how it relates to learning, more research gets us closer to understanding it, one article at a time.

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Appendices

Appendix A

Time-frequency maps of the male participant HF with the selected brain regions in frontal, central, parietal, temporal, and occipital areas. The y-axes show the amplitude (signal magnitude), in frequencies ranging from 2 to 60 Hz, which represent estimated neural act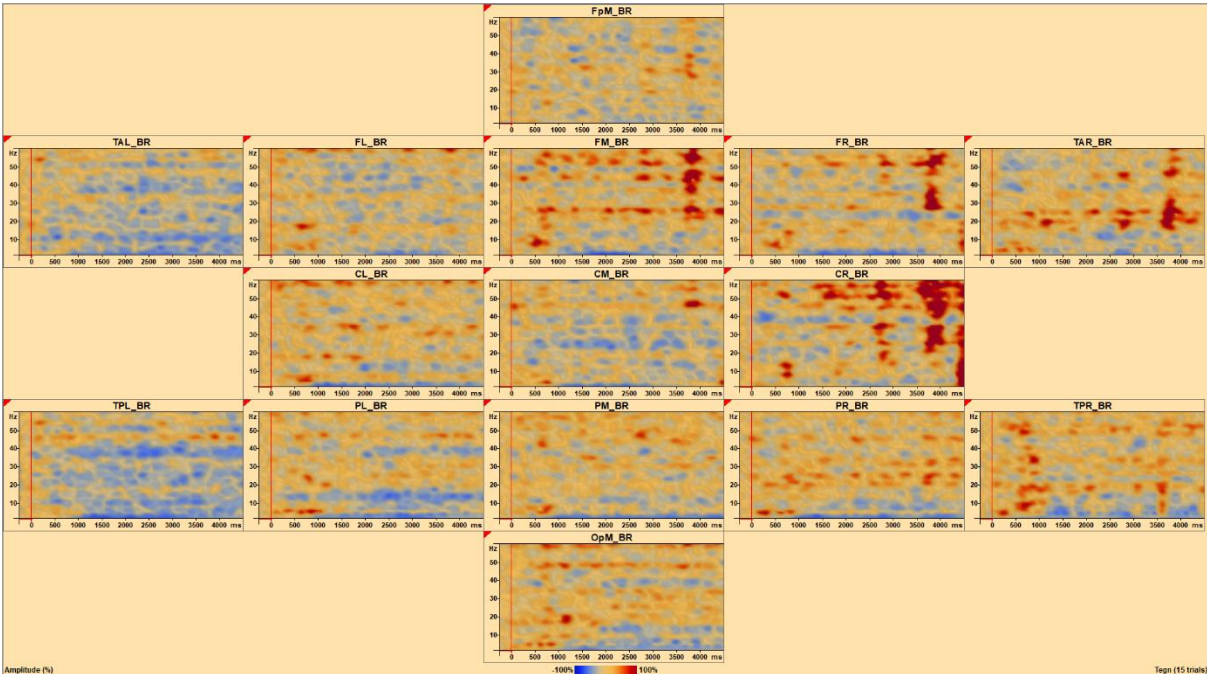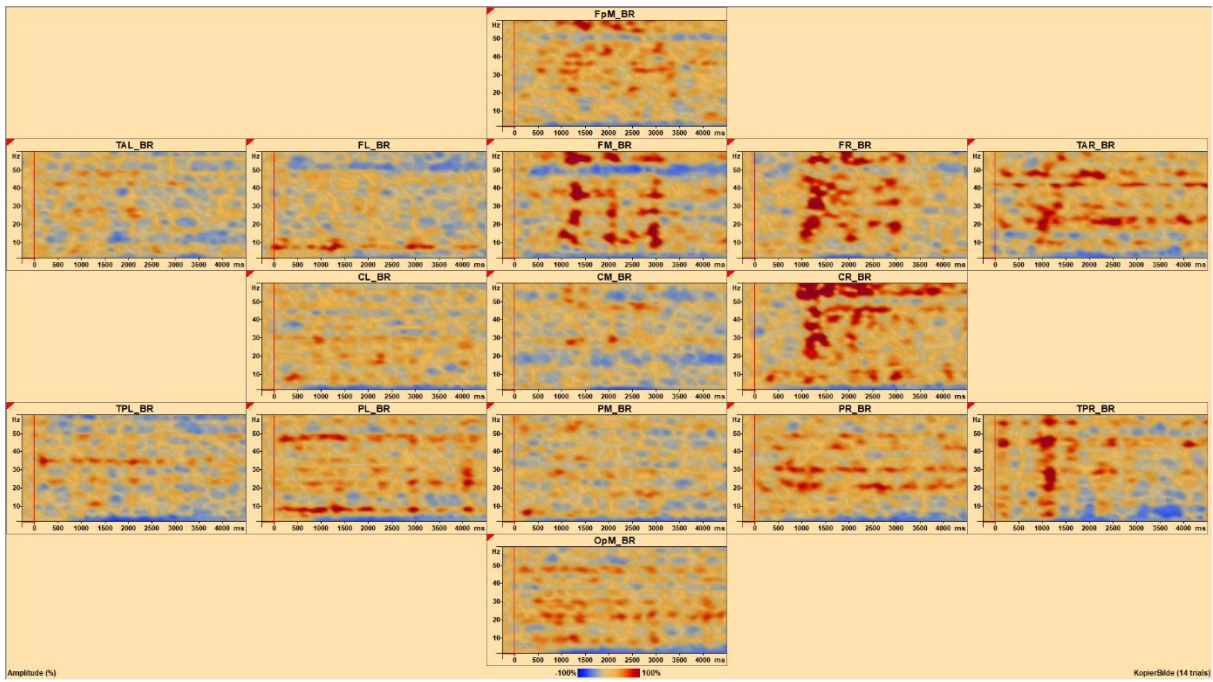ivity across the brain regions compared to baseline (-250 to 0 ms) in the conditions draw, copy a drawing, describe, and copy text. Baseline activity and 4500 ms recording time is shown on the x-axes, with trial onset indicated by a red line. Red areas indicate synchronization (ERS), whereas blue areas indicate desynchronization (ERD) of the brain activity.
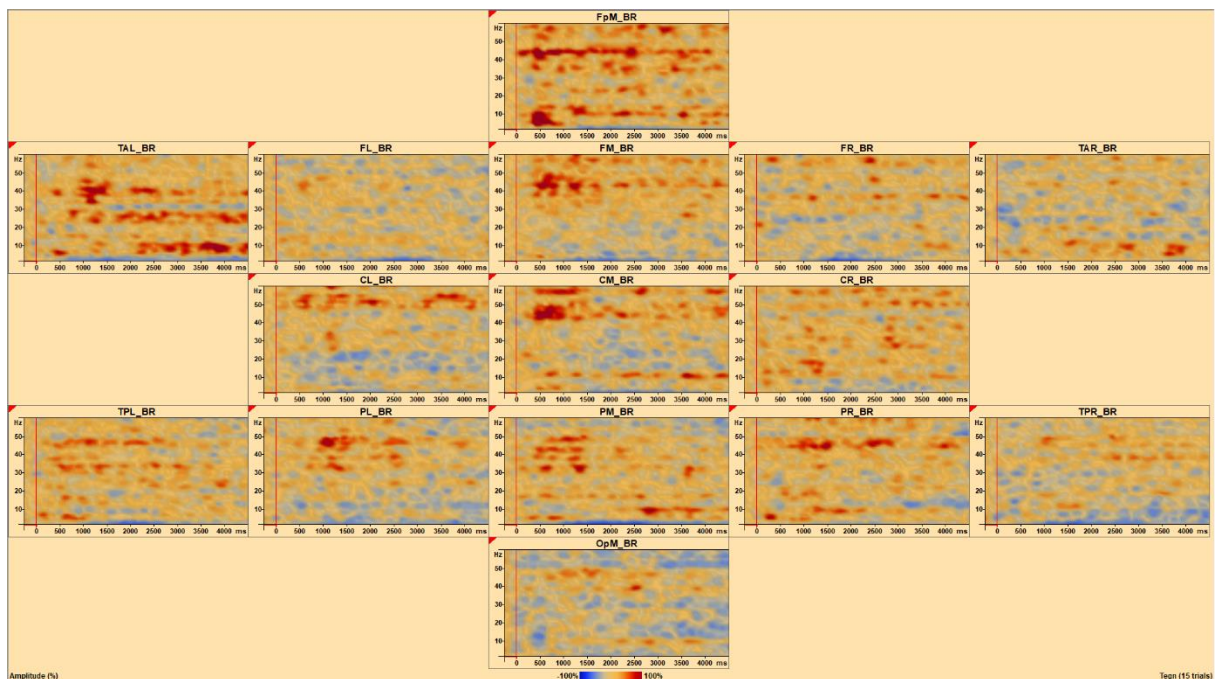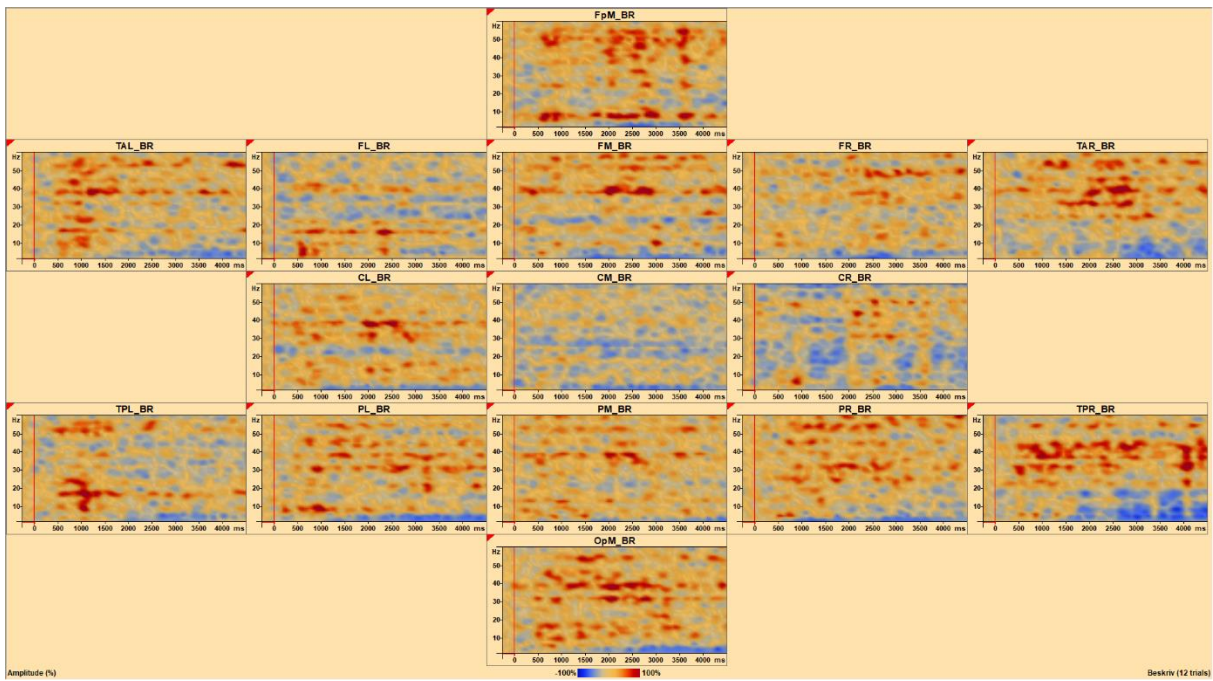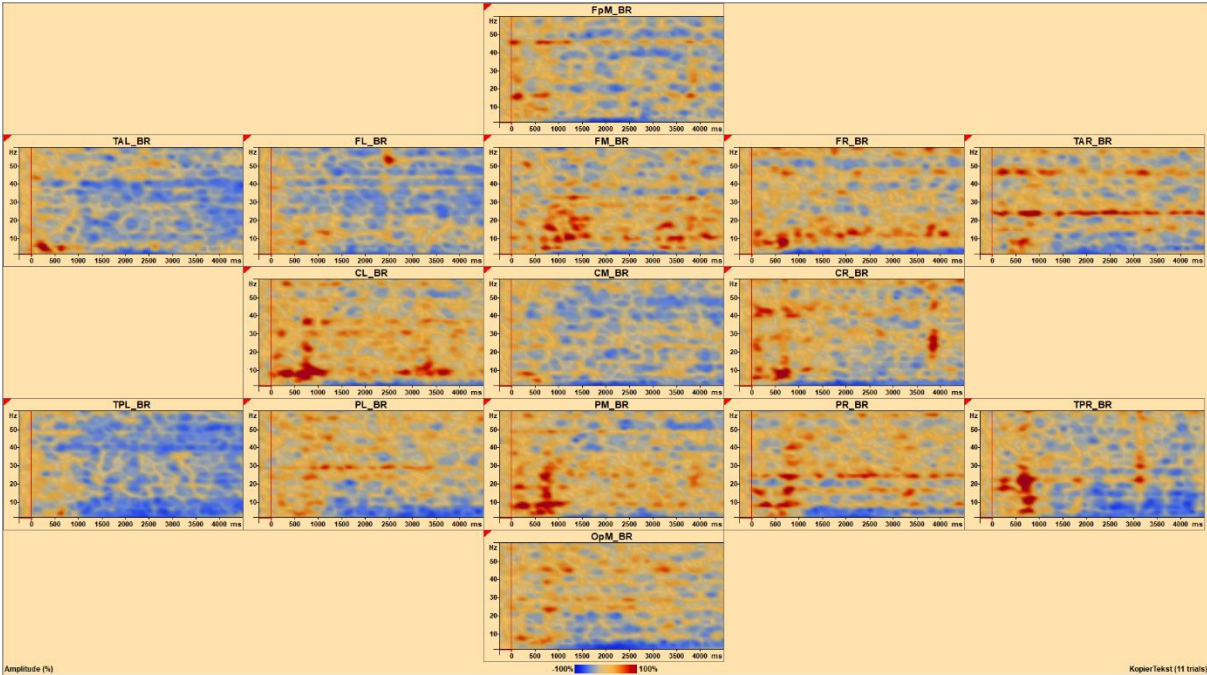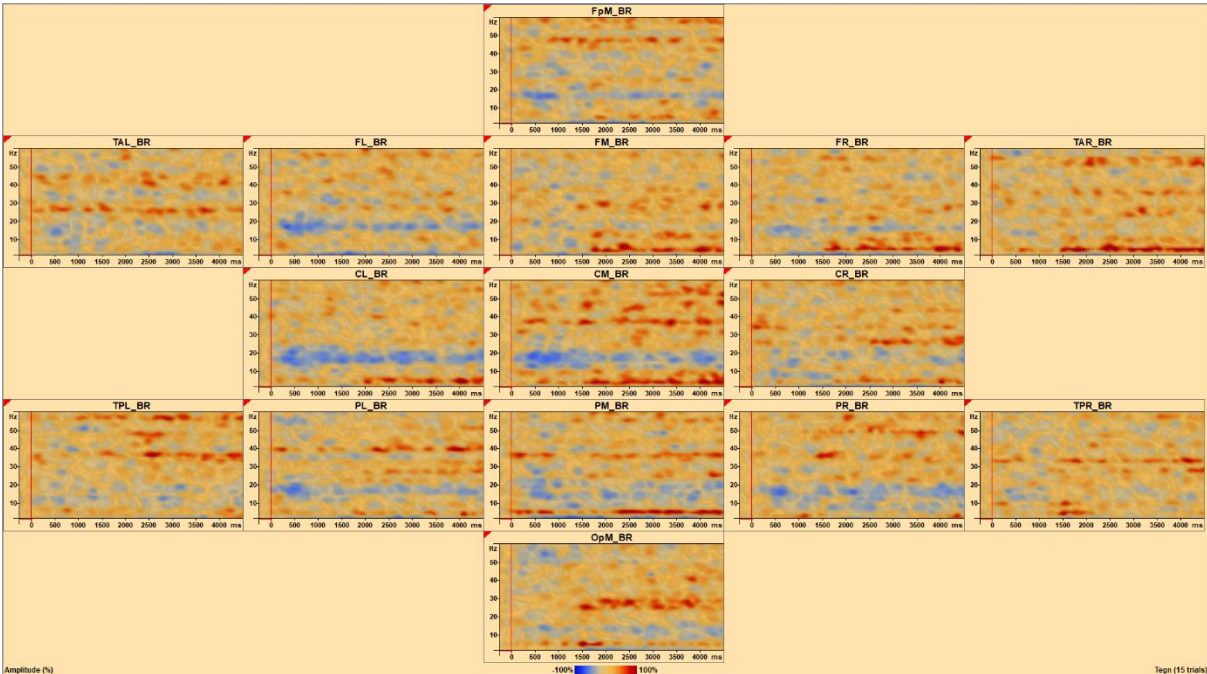
Draw:

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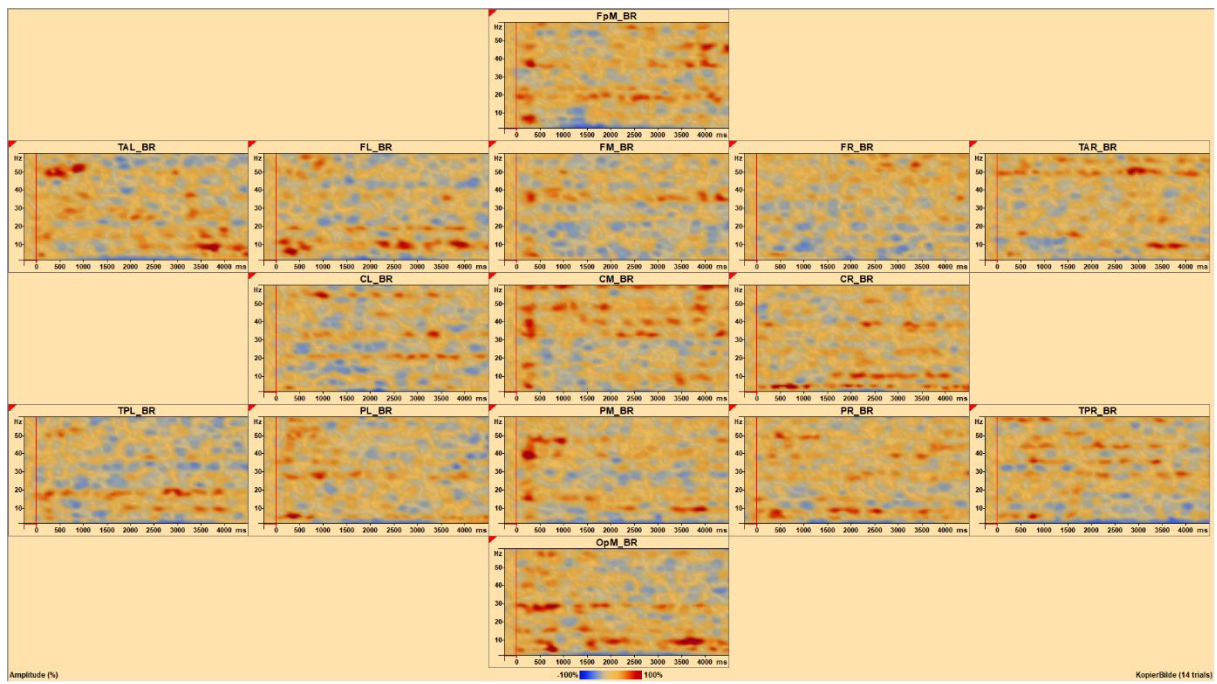
Describe:
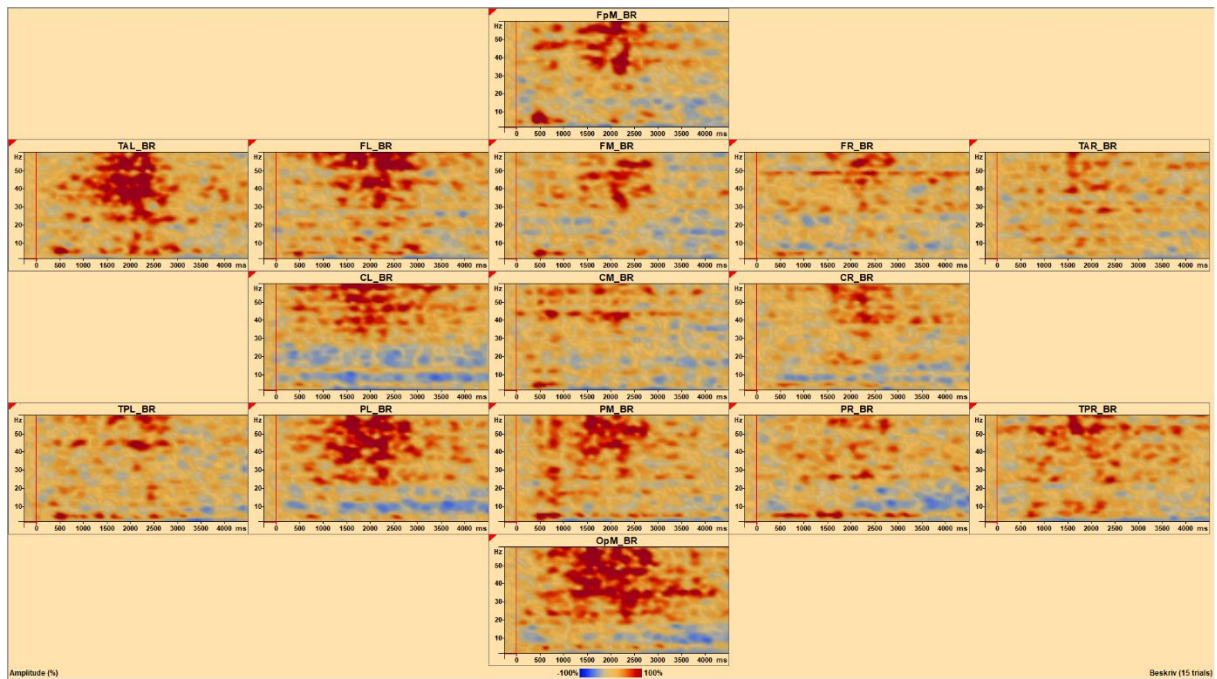
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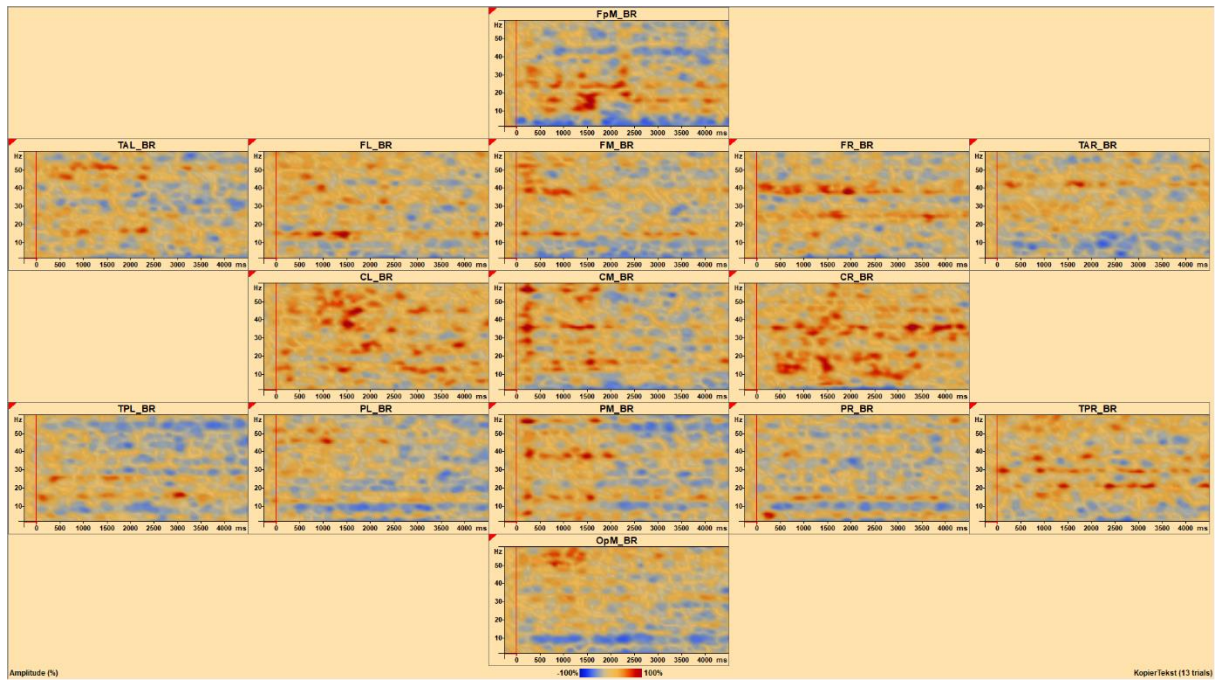
Appendix B

Time-frequency maps of the female participant I with the selected brain regions in frontal, central, parietal, temporal, and occipital areas. The y-axes show the amplitude (signal magnitude), in frequencies ranging from 2 to 60 Hz, which represent estimated neural activity across the brain regions compared to baseline (-250 to 0 ms) in the conditions draw, copy a drawing, describe, and copy text. Baseline activity and 4500 ms recording time is shown on the x-axes, with trial onset indicated by a red line. Red areas indicate synchronization (ERS), whereas blue areas indicate desynchronization (ERD) of the brain activity.

Draw:
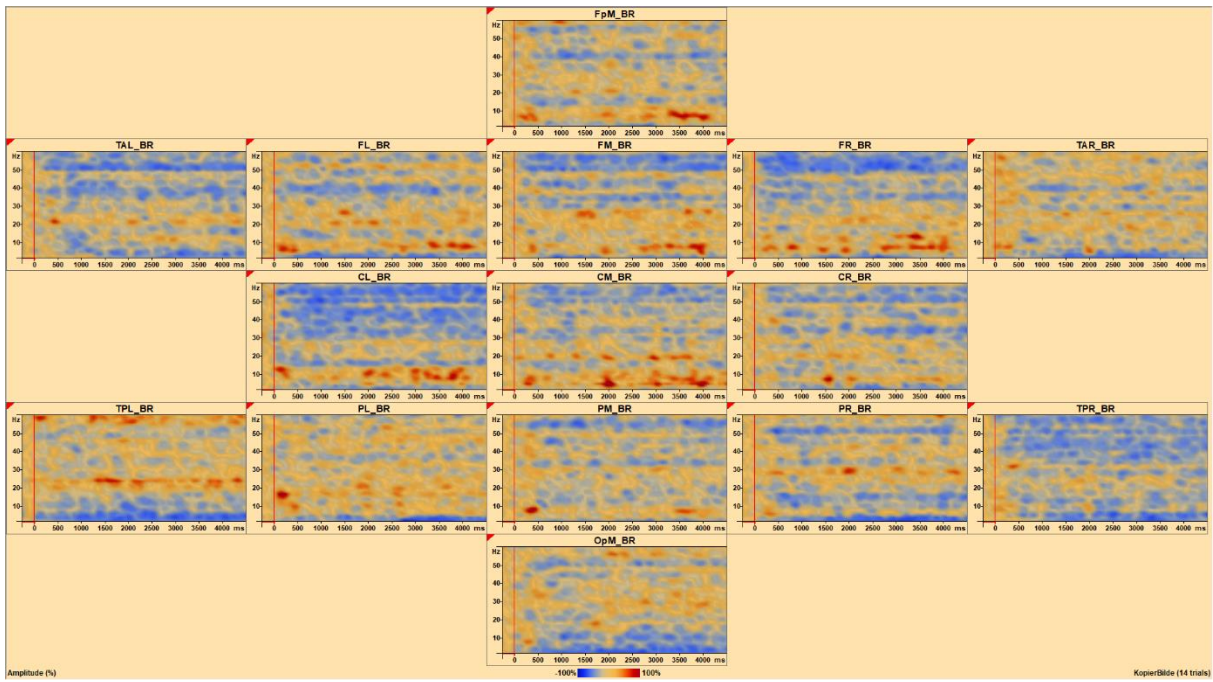
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Appendix C

Time-frequency maps of the female participant T with the selected brain regions in frontal, central, parietal, temporal, and occipital areas. The y-axes show the amplitude (signal magnitude), in frequencies ranging from 2 to 60 Hz, which represent estimated neural activity across the brain regions compared to baseline (-250 to 0 ms) in the conditions draw, copy a drawing, describe, and copy text. Baseline activity and 4500 ms recording time is shown on the x-axes, with trial onset indicated by a red line. Red areas indicate synchronization (ERS), whereas blue areas indicate desynchronization (ERD) of the brain activity.
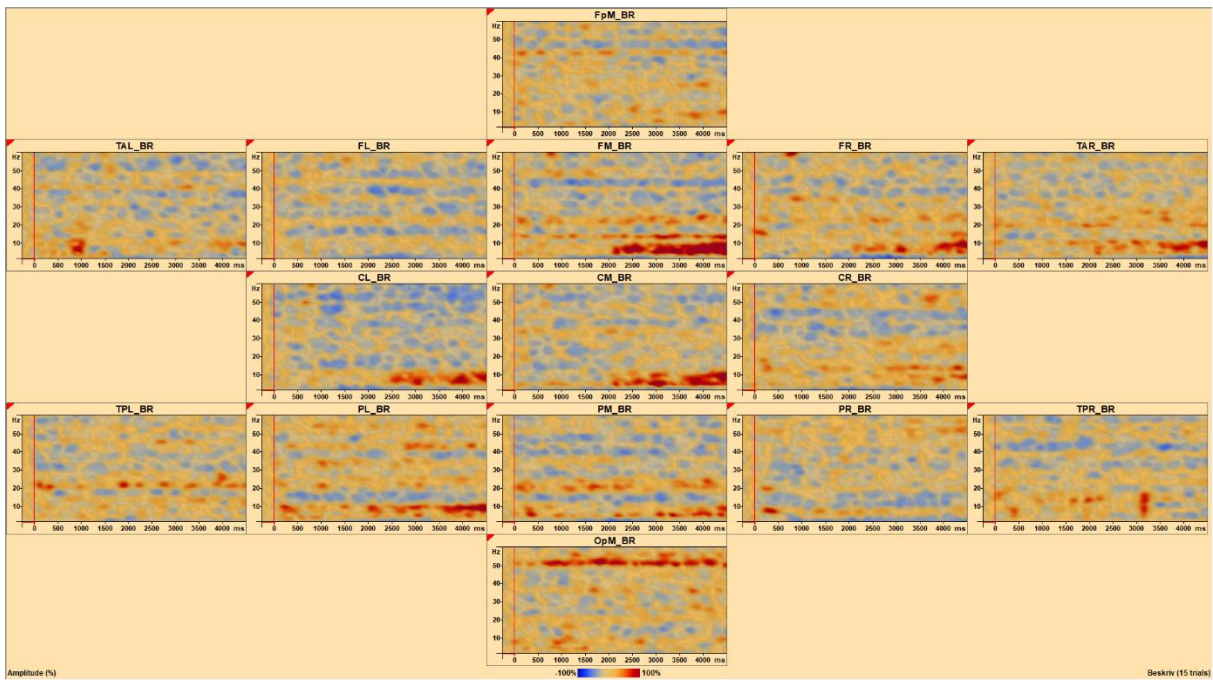
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