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Fixation-related EEG frequency band power analysis: A promising methodology for studying instructional design effects of multimedia learning material

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Abstract

During the last decade the combined recording of eye-tracking data and electroencephalographic (EEG) data has led to the methodology of fixation-related potentials analysis (FRP). This methodology has been increasingly and successfully used to study EEG correlates in the time domain (i.e., event-related potentials, ERPs) of cognitive processing in free viewing situations like text reading or natural scene perception. Basically, fixation-onset serves as time-locking event for epoching and analysing the EEG data. In this article the methodology of fixation-related frequency band power analysis (FRBP) is proposed and conceptually outlined to study cognitive load and affective variations in learners during free viewing situations of multimedia learning materials (i.e., combinations of textual and pictorial elements). The EEG alpha frequency band power at parietal electrodes may serve as a valid measure of cognitive load, whereas the frontal alpha asymmetry may serve as a measure of affective variations. I will introduce and motivate the measures and the methodology and discuss methodological challenges and potential ways to overcome them. The methodology is frontline for learning research, first, as to date the EEG has been rarely used to study design effects of multimedia learning materials and second, as fixation-related EEG data analysis has rarely been done focussing on the frequency domain (i.e., FRBP). Despite methodological challenges still to be solved, FRBP may provide a more in-depth picture of cognitive processing during multimedia learning compared to eye-tracking data or EEG data in isolation and thus may help clarifying effects of multimedia design decisions.

Keywords: EEG; eye-tracking; fixation-related EEG data analysis; EEG alpha frequency band power; multimedia

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1. Introduction

There is general agreement in instructional psychology that an adequate design of multimedia learning material (i.e., combinations of text and picture) is crucial for learning success (e.g., Mayer, 2009). This is because the design of multimedia learning material can alter the amount of additional, extraneous cognitive load (CL) imposed on the learner, either, in case of "good" design by freeing working memory resources, or, in case of "bad" design, by depleting working memory resources, potentially leading to an overload-situation hampering successful learning (see theoretical accounts like the Cognitive Load Theory, Sweller, van Merrienboer, & Paas, 1998; or the Cognitive Theory of Multimedia Learning, Mayer, 2009). Various multimedia design principles have been described that may alter learners' extraneous CL (Mayer & Fiorella, 2016; Mayer & Moreno, 2003).

However, it still remains a matter of research of how exactly CL is influenced by certain multimedia elements and multimedia design decisions. For example, how exactly adding decorative pictures to learning materials (i.e., texts) influence cognitive (and affective) processing and consequently alter learning outcomes is still a matter of debate (for a comprehensive review see Rey, 2012). Such decorative pictures (or graphical elements) adjacent to textual information in multimedia learning materials that are only loosely content-related (e.g., a picture of a lightning stroke adjacent to a text describing the meteorological formation of thunderstorms) have been termed *pictorial seductive details* (Harp & Mayer, 1998). Pictorial seductive details have resulted in mixed effects on learning outcomes, ranging from beneficial effects (Schneider, Nebel, & Rey, 2016), to no-effects (Park & Lim, 2007), and even detrimental effects (Harp & Mayer, 1998; Mayer & Fiorella, 2016). While the beneficial effects might be explained by affective processes with the pictures positively altering the learners' motivational state (Knörzer, Brünken, & Park, 2016; Lenzner, Schnotz, & Müller, 2013; Magner, Schwonke, Aleven, Popescu, & Renkl, 2014; Schneider et al., 2016), detrimental effects might be explained by increased extraneous CL due to the additional, yet irrelevant pictorial information (Mayer & Fiorella, 2016; Mayer & Moreno, 2003), and due to effects of distraction away from and interruption of the learning process (i.e., schema construction; Schneider, Dyrna, Meier, Beege, & Rey, 2017).

Clearly, in order to unravel potential reasons for the disparate effects of pictorial seductive details, adequate process measures (i.e., online measures) are necessary to better understand the effects of multimedia design elements on cognitive and affective processing. The electroencephalogram (EEG) and more precisely the EEG alpha and theta frequency band power might serve as such adequate, promising process measures. Especially, the methodology of fixation-related EEG frequency band power analysis (FRBP) might allow studying the EEG data in ecological valid task settings, that is, in free viewing situations of multimedia learning material, and may allow identifying which multimedia elements (i.e., text or picture) alter CL to what extent. In the next section, I will introduce the EEG alpha (and theta) frequency band power as potential and promising measures of CL and affective processing. I will then describe the FRBP methodology on a conceptual level and address open methodological challenges as well as possible approaches to overcome them. Note that the main purpose of the current article is to conceptually propose the FRBP analysis as a promising, new methodological account for multimedia research by providing an overview of the EEG frequency band power as a measure of CL and affective processing and by making readers aware of potentials as well as weaknesses of the FRBP methodology, yet without discussing practicalities and single methodological challenges in depth. The article may nevertheless serve as a valid and helpful primer for future research using the FRBP methodology in the context of multimedia materials.

2. EEG frequency band power as a measure of cognitive load and affective processing

Identifying adequate process measures still is an important and general matter of debate in instructional psychology (Brünken, Seufert, & Paas, 2010; Paas, Tuovinen, Tabbers, & van Gerven, 2003). Traditionally, most research focused on outcome measures like learning success, retention, or transfer of the learned knowledge. Subjective rating scales are used to assess the learners' invested effort during learning (e.g., Hart & Staveland, 1988; Klepsch, Schmitz, & Seufert, 2017; Paas, 1992) with effort sought to be directly related to CL and hence working memory load (Schnotz & Kürschner, 2007). One general drawback of subjective rating scales is that they only allow assessing CL in hindsight and for longer time periods. Whether participants report an averaged impression of CL or certain load-peaks remains elusive (Schmeck, Opfermann, van Gog, Paas, & Leutner, 2015). More importantly, motivational factors might confound the subjective ratings of CL (Schnotz et al., 2009). Consequently, the use of objective, online process measures of CL during learning have been proposed (Antonenko, Paas, Grabner, & van Gog, 2010; Brünken, Plass, & Leutner, 2003; Korbach, Brünken, & Park, 2017; Paas et al., 2003). For example, performance in a parallel secondary task can be used to assess the current CL of the primary task (Brünken et al., 2003; Park & Brünken, 2015). However, the secondary task may unintentionally interfere with the primary task. In contrast, physiological measures like pupil dilation or the EEG, and, more specifically, the EEG alpha (8 – 13 Hz) frequency band power at parietal electrodes and the theta (4 – 6 Hz) frequency band power at frontal electrodes may serve as valid measures of CL overcoming the aforementioned limitations (Antonenko et al., 2010; Beatty & Lucero-Wagoner, 2000). In addition, the frontal alpha asymmetry (FAA; Smith, Reznik, Stewart, & Allen, 2017) might serve as an index of affective effects in multimedia task materials.

The human EEG is typically recorded via several (e.g., 32 or 64) electrodes that are placed on the scalp at different positions consistently defined by the (extended) international 10-20 system (Jasper, 1958) using electrode caps with predefined slots for the electrodes (see Figure 1 for an exemplary electrode layout). After applying electrode gel to reduce the electrical impedance between the electrodes and the skin, the raw EEG can be measured. The EEG is the amplified recording of the small electrical currents generated within the brain by the summed post-synaptic electrical potentials of large neuronal assemblies consisting of several millions of neurons (pyramidal cells of the cortex) that are oriented in parallel and synchronously active (for reviews see Cohen, 2017; Jackson & Bolger, 2014; Olejniczak, 2006). The typical sampling rate of an EEG recording device is 500 or 1000 Hz (i.e., one measurement point every two or each millisecond, respectively). The EEG thus reflects the oscillatory activity of specific neuronal populations with excellent time resolution, yet the spatial resolution is rather low (in the range of centimeter; Olejniczak, 2006).

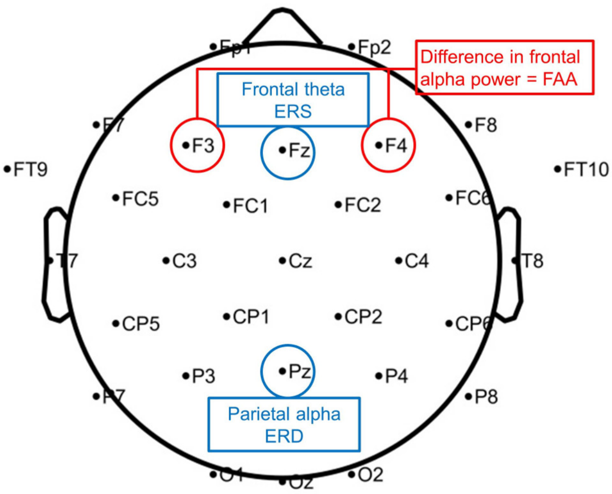

Figure 1. Schematic head (nose up) with exemplary electrode layout. Highlighted are representative electrode positions for measuring CL (blue color) or affective processing (red color). Note. Electrodes outside the head are due to the projection of 3D locations in 2D space.

After some data preprocessing steps (e.g., filtering, artefact removal; for guidelines see Picton, 2000), the recorded EEG data can be analyzed in the time domain and/or in the frequency domain. For analyses in the time domain, parts of the EEG (i.e., epochs) time-locked to certain events (e.g., stimulus-onsets) are averaged across several trials (i.e., repetitions of a specific event) to increase the signal-to-noise ratio. This procedure results in so-called event-related potential (ERP) curves, that is, positive and negative deflections (i.e., components) that have been linked quite specifically to certain cognitive processes (for a comprehensive review see Münte, Urbach, Düzel, & Kutas, 2000). For analyses in the frequency domain, the spectrum is calculated for the EEG epochs of interest (e.g., using fast-fourier transforms, FFT, or wavelet analysis; Cohen, 2014). This results in power values for the different frequencies contained in the EEG signal (and also phase information, which however is beyond the scope of the current article; the interested reader may refer to Bastiaansen, Mazaheri, & Jensen, 2012; Cohen, 2014). The more neurons are synchronously active (i.e., 'firing') at a specific frequency in response to an event, the higher is the measured power (i.e., amplitude to the square) at this specific frequency. Therefore, an increase in frequency band power after an event is generally termed event-related synchronization (ERS), whereas a decrease in frequency band power is termed event-related desynchronization (ERD; Pfurtscheller & Lopes da Silva, 1999). The amount of change in ERD or ERS in relation to an event can be expressed as percentage of change using the ERD/ERS%-formula given in Pfurtscheller & Lopes da Silva (1999; see also Antonenko et al., 2010). Five frequency bands have traditionally been differentiated in the EEG reflecting functionally different oscillatory neuronal activity: Slow oscillatory activity in the delta (< 3 Hz) range, oscillatory activity in the theta (4 – 6 Hz), alpha (8 – 13 Hz), and beta (13 – 24 Hz) range, and fast oscillatory activity in the gamma (> 40 Hz) range (for reviews see Bastiaansen et al., 2012; Krause, 2003). In the context of multimedia research oscillatory activity (and hence, power) in the theta and alpha frequency band is of specific interest as will be detailed below. Slow (delta) and fast (gamma) oscillatory activity are rather prone to artefacts (e.g., slow drifts or muscle activity) requiring highly controlled lab settings and rather simple, basic tasks and task materials (see, e.g., Bastiaansen et al., 2012), thus being rather inadequate for multimedia research. Oscillatory activity in the beta band has mainly been attributed to reflect activity of the motor cortex (Pfurtscheller, Zalaudek, & Neuper, 1998), but might be also interesting for studying cognitive processes (Engel & Fries, 2010).

Importantly, the EEG alpha and theta frequency band power might be used as reliable process measures of CL in multimedia research. It has been consistently observed that the EEG alpha frequency band power at parietal electrodes decreases for increasing CL whereas the frontal-central EEG theta frequency band power increases for increasing CL (Gevins & Smith, 2000; Kretzschmar et al., 2013; Palomäki, Kivikangas, Alafuzoff, Hakala, & Krause, 2012; Pesonen, Hämäläinen, & Krause, 2007; AUTHORS). Functionally, the alpha ERD (i.e., the decreasing alpha power) has been interpreted to index cortical activity related to attentional and memory processing (Klimesch, 1999; Krause, 2003). According to Klimesch (1999) the alpha frequency band might be functionally divided further in an upper alpha (10 – 13 Hz) frequency band that might mainly be related to (semantic) memory processing and a lower alpha (8 – 10 Hz) frequency band that might mainly be related to attentional processes. Neural activity in the EEG theta frequency band has been associated predominantly with processes of working memory and cognitive control (Itthipuripat, Wessel, & Aron, 2013; Nigbur, Ivanova, & Stürmer, 2011; Sauseng et al., 2002; Sauseng, Griesmayr, Freunberger, & Klimesch, 2010). Note however, that the functional relationship between EEG frequency band power and specific cognitive processes is not as clear and well established as the relationship between certain ERP components of the EEG and cognitive processes (Krause, 2003). However, in contrast to ERPs that require a highly controlled, artificial task environment, especially EEG alpha frequency band power has been shown to reliably index CL also in complex task materials like those of instructional psychology (Antonenko & Niederhauser, 2010; Gerlic & Jausovec, 2001; AUTHORS). Importantly, changes in the EEG frequency band power index fluctuations of CL with high temporal acuity.

Furthermore, apart from indexing CL the EEG alpha frequency band power might also be used to assess emotional and motivational aspects of stimulus-processing. The frontal alpha asymmetry (FAA) may serve as such a measure. The FAA is a relational measure of the EEG alpha (8 – 13 Hz) frequency band power over the left-frontal hemisphere compared to the right-frontal hemisphere, commonly calculated as the difference between corresponding electrodes (e.g., F4 minus F3; Smith, Reznik, Stewart, & Allen, 2017). The FAA has its origin in cortical activity of the prefrontal cortex. The prefrontal cortex plays an important role in affective processing and emotion regulation showing specific left and right hemispheric lateralization effects for emotions and affective stimulus content (Demaree, Everhart, Youngstrom, & Harrison, 2005; Dixon, Thiruchselvam, Todd, & Christoff, 2017). Although still matter of debate, greater left than right hemispheric cortical activity has been associated with approach motivation and hence predominantly emotionally positively connoted stimuli, whereas greater right hemispheric cortical activity has been associated with withdrawal motivation and hence predominantly emotionally negatively connoted stimuli (Ahern & Schwartz, 1985; Harmon-Jones, Gable, & Peterson, 2010). Most EEG studies so far assessed the FAA during rest conditions after emotion induction procedures (e.g., Coan & Allen, 2004). Yet, recent research indicated that the FAA might be also used during task performance when emotional stimuli are presented for a brief period of time (Schöne, Schomberg, Gruber, & Quirin, 2016; Weinreich, Stephani, & Schubert, 2016). Thus, potentially, the FAA might be used to study affective aspects of multimedia. Whether the FAA can be used in such a way for complex multimedia materials has however to be studied further.

The methodology of fixation-related EEG data analysis may allow analyzing the EEG frequency band power in free viewing situations of multimedia task materials when certain elements (i.e., areas of interest, AOIs) are fixated and thus may allow to assess how CL (or in case of the FAA, affective processing) is altered by specific multimedia elements like pictorial seductive details. In the next section, I will give a brief overview on the methodology, then conceptually pointing out methodological challenges that one has to be aware of.

3. Fixation-related EEG data analysis

Eye-tracking is increasingly used in research on instructional multimedia materials to study underlying cognitive processes during learning (e.g., Eitel, Scheiter, & Schüler, 2012; Hyönä, 2010; Jarodzka, Holmqvist, & Gruber, 2017; Mayer, 2010; Schüler, 2017; Van Gog & Scheiter, 2010; for a recent overview on the literature see Alemdag & Cagiltay, 2018). Eye-tracking data shows the movement of the eyes, basically differentiating between saccades (i.e., the eyes quickly moving) to elements of the visual scenery and fixations (i.e., the eyes practically at rest) on elements of the visual scenery (for a comprehensive discussion of different eye-tracking patterns see Holmqvist & Andersson, 2017). It is generally agreed on, that during saccades the visual information intake is not possible (e.g., Kok & Jarodzka, 2017a), whereas it is possible (and most of the time takes place) during fixations. It has been shown that the fixation patterns vary depending on the task materials and the given task (e.g., in picture viewing, Yarbus, 1967, or in reading, Strukelj & Niehorster, 2018; for reviews see Kowler, 2011; Rayner, 1998; 2009), indicating a plausible link between fixations and cognitive processing (Just & Carpenter, 1976; 1980). Note however, this link might not always be straightforward. Visual attention might be slightly ahead of what is fixated (depending on the task, up to 250 ms; Deubel, 2008). In addition, due to peripheral viewing especially in reading more elements than those fixated at might be processed (Baccino & Manunta, 2005; Dimigen, Kliegl, & Sommer, 2012; Rayner, 2009). On the contrary, what is fixated at might not always be (consciously) processed. This might be the case during periods of mind-wandering (Foulsham, Farley, & Kingstone, 2013), or if visual elements are not task relevant (as indicated in change blindness paradigms; e.g., Triesch, Ballard, Hayhoe, & Sullivan, 2003). Nevertheless, fixations have been used as a valid proxy reflecting the individuals' structure of the information intake (and procesing) in free viewing situations and hence as triggers for defining epochs in time for which the EEG data can be analysed.

In free viewing or free reading situations no specific stimulus-onset exists. However, the fixation-onset can be used as event for which the EEG data is time-locked, epoched, and analysed to (depending on the concrete research question, some studies also used saccade-onset as time-locking event; cf. Dimigen, Sommer, Hohlfeld, Jacobs, & Kliegl, 2011). Most studies so far have studied the EEG in the time domain, that is, fixation-related potentials (FRPs), for example in reading research (Dimigen, et al., 2011; Frey, Lemaire, Vercueil, & Guérin-Dugué, 2018; Henderson, Luke, Schmidt, & Richards, 2013; Hutzler et al., 2007; Kliegl, Dambacher, Dimigen, & Sommer, 2014; Kornrumpf, Dimigen, & Sommer, 2017; Kornrumpf, Niefind, Sommer, & Dimigen, 2016; Léger et al., 2014; Niefind & Dimigen, 2016; Weiss, Knakker, & Vidnyánszky, 2016), natural scene perception (Giannini, Alexander, Nikolaev, & van Leeuwen, 2018; Simola, Le Fevre, Torniainen, & Baccino, 2015; Simola, Torniainen, Moisala, Kivikangas, & Krause, 2013), visual search

(Brouwer, Hogervorst, Oudejans, Ries, & Touryan, 2017; Kamienkowski, Ison, Quiroga, & Sigman, 2012; Kaunitz et al., 2014; Ries, Touryan, Ahrens, & Connolly, 2016; Winslow et al., 2010), decision making (Frey et al., 2013), and human-computer interaction (Léger et al., 2014). Despite methodological challenges (see below) these studies concurrently report FRP-effects comparable to classical ERP-effects (e.g., N400-like effects for word predictability; Dimigen et al., 2011), thus validating the feasibility and meaningfulness of fixation-related EEG data analyses.

Only few studies so far have analysed the EEG data in the frequency domain using FRBP. For example, AUTHORS and colleagues (AUTHORS, Experiment 1) used FRBP to study CL during hypertext-like reading, comparing several parts of a text that defined two different areas of interest (AOIs): AOIs of parts of the text where participants simply read and AOIs of parts of the text where participants additionally had to perform hyperlink-like selection processes. As hypothesized, the CL was higher when participants had to perform hyperlink-like selection processes in addition to purely text reading, indicated by decreased EEG alpha frequency band power. Interestingly, this result was also confirmed by the pupil dilation data, with the pupil showing a larger diameter (i.e., higher CL) for parts of the text with hyperlink-like selection processes as compared to purely text reading. In a second experiment (AUTHORS, Experiment 2) the results could be replicated using classical response-locked EEG data analysis instead of fixation-related EEG data analysis, thus underlining the validity of the fixation-related EEG data analysis methodology. Another study by AUTHORS and colleagues (AUTHORS) used FRBP to study CL (as indexed by the parietal EEG alpha frequency band power) in free viewing and evaluating of search engine result pages. This study indicated that a perfect hit (i.e., a semantically and lexically matching search result for a specific search query) resulted already during initial fixations in decreased EEG alpha frequency band power as compared to search results that are no, or no perfect matches for a given search query. This has been interpreted as indicating that the best hit is recognized early in time and potentially then more thoroughly processed (resulting in increased CL) as compared to other, less fitting search results. Finally, Vignali and colleagues (Vignali, Himmelstoss, Hawelka, Richlan, & Hutzler, 2016) used FRBP to study semantic violations in sentences in free reading situations. They observed decreased lower-beta band (13-18 Hz) power for fixations of semantically unrelated words as compared to semantically related words, also indicating higher CL.

To sum up, studies so far indicated the principal feasibility and validity of the methodology of fixation-related EEG data analysis. Combining eye-tracking and the EEG in research on instructional multimedia materials seems to be promising for two reasons. First, it allows to study the EEG during learning with multimedia task materials in task settings of high ecological validity (i.e., 'realistic' task materials, with texts and pictures presented simultaneously on one screen). Without this methodology, text and pictures would have to be presented separately in time (i.e., in rather artificial sequences) to create stimulus-onsets for the EEG data analysis. Second, the EEG data might be used as an additional measure for triangulating the meaning of observed eye-movement patterns as has been proposed for verbal data (Kok & Jarodzka, 2017b). For example, the EEG might help differentiating whether longer fixations might indicate increased CL (König et al., 2016; Reichle & Reingold, 2013) or individuals' expertise (Bertram, Helle, Kaakinen, & Svedström, 2013; Reingold & Sheridan, 2011), or it might help differentiating whether learners are still working on a (difficult) task or mind-wandering (Foulsham et al., 2013). Yet, some methodological challenges remain that one has to be aware of.

4. Methodological challenges of fixation-related EEG data analysis and potential solutions

There are some challenges that one has to be aware of when analysing fixation-related EEG data. First, the EEG and eye-tracking data has to be synchronized. This can be done by regularly sending triggers (e.g., each second) during data recording to both recording devices (i.e., the EEG and the eye-tracker). Based on these triggers the two data streams can then be synchronized offline using for example the toolbox EEGLAB (Delorme & Makeig, 2004) with the EYE-EEG plugin (Dimigen et al., 2011). The synchronisation of the EEG and eye-tracking data includes matching the sampling rates of both data streams (which is for the EEG typically at 500 Hz or 1000 Hz and for current remote eye-tracking devices at 120 Hz or 250 Hz), either by up- or down-sampling.

Once the EEG data and the eye-tracking data are synchronized there remain several challenges that have to be taken into consideration. These include the correction of eye-movement artefacts, dealing with overlapping EEG data segments due to different and rather short fixation durations, and the selection of an adequate baseline (for a comprehensive discussion of these challenges and potential solutions the interested reader may refer to Baccino, 2011; Dimigen et al., 2011; Nikolaev et al., 2016; the purpose of the current article is to make readers aware of potentials as well as weaknesses of the methodology, yet without discussing single methodological challenges in depth).

Eye-movements (i.e., saccades and blinks) alter the electric fields around the eyes and consequently confound the raw EEG, especially at frontal electrodes (Iwasaki et al., 2005). Thus, eye-movement artefacts may either mask the EEG correlates of interest or, worse, may induce a systematic error. For example, in multimedia the eye-movement patterns vary between viewing of textual and pictorial elements. Thus, when interested in fixation-related EEG data for multimedia, that is, when comparing EEG data for text reading and picture viewing, the EEG may be confounded by different eye-movement patterns. However, several methodologies exist to clean the raw EEG data from eye-movement artefacts (for reviews see Croft & Barry, 2000; Islam, Rastegarnia, & Yang, 2016). For example, independent component analysis (ICA) can be used to reliably identify and correct for eye-movement artefacts (Chaumon, Bishop, & Busch, 2015; Delorme, Sejnowski, & Makeig, 2007; Jung et al., 2000; Zhou & Gotman, 2009). Noteworthy, especially in the context of fixation-related EEG data analysis the use of ICA has been shown to result in adequately cleaned EEG, outperforming other methodologies like standard regression-based data cleaning (Henderson et al., 2013; Hutzler et al., 2007).

While a variety of methodologies exists for cleaning EEG data from eye-movement artefacts, the varying and rather short length of fixations is another challenge for fixation-related EEG analysis that one has to be aware of. For example, during reading typical fixations last on average between 200-250 ms (e.g., Dimigen et al., 2011). This is problematic when analysing the EEG data in the time domain as later components in the FRP of a current fixation (e.g., the N400) might be overlapped (i.e., confounded) by early components of the FRP of the following fixation. In FRP analysis very short fixations are therefore excluded from analysis (e.g., fixations < 80 ms; Frey et al., 2018). Several statistical methods (e.g., regression-based models) have been proposed to deal with the potentially confounding effect of overlapping EEG data segments (Baccino, 2011; Dimigen et al., 2011; Frey et al., 2018; Nikolaev, Pannasch, Ito, & Belopolsky, 2014). It has also been proposed to compare only those data sequences of comparable fixation-patterns between task conditions of interest to minimize potentially confounding effects due to different fixation durations and hence differently overlapping EEG segments (Nikolaev et al., 2016). While this proceeding might be feasible for task conditions that are quite comparable (e.g., both within the domain of reading), for multimedia task materials with texts and pictures it might be impossible to adequately match the fixations used for analysis due to the different fixation patterns for reading and picture viewing. Moreover, in FRBP analysis overlapping EEG data epochs due to short fixation durations might frequently occur. This is because, the length of the EEG data epoch defines the possible frequency resolution of the calculated spectrum. For example, in the theta frequency range (4 – 6 Hz) one oscillation lasts at minimum 250 ms. Thus, when interested in the theta frequency band power an analysis window of at least 250 ms would be necessary. Commonly, an analysis window including several oscillations of the specific frequency of interest is recommended for calculating the spectrum (i.e., an analysis window of at least 500 ms length). Consequently, one has to be aware of the constraint that FRBP analysis is seldom suitable for analysing the EEG data for single fixations (unless their duration is long enough). Yet for research on multimedia task materials interested in CL this constraint might not be of too much relevance, as the AOIs of interest (i.e., parts of the text versus the pictures) might generally comprise several fixations that one could summarize, resulting in EEG data epochs long enough for analysis (see Figure 2). Importantly, one still would be able to differentiate between first and later visits of an AOI. Nevertheless, a comparison of the EEG in classical sequential stimulus presentation paradigms (e.g., in multimedia research by presenting text and pictures sequentially) with fixation-related paradigms might be necessary to further validate the reliability of the FRBP analysis when used in new experimental paradigms or for new, complex multimedia task materials.

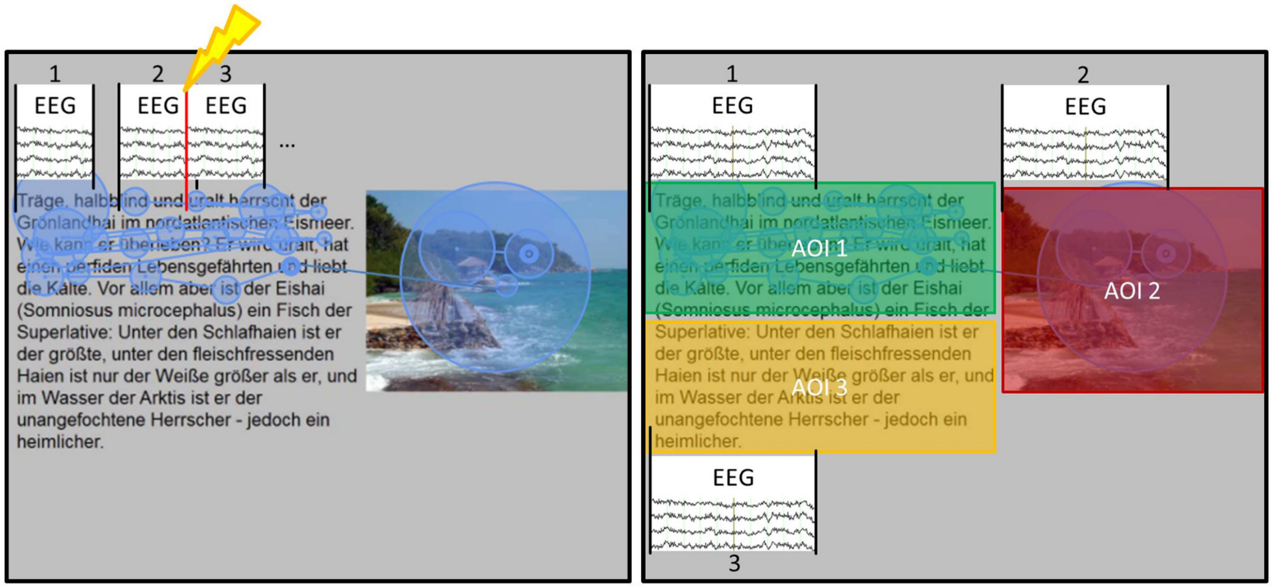

Figure 2. Left part: Schematic illustration of the problem of overlapping EEG data segments (marked by the lightning symbol) in case of short fixations and a FRBP analysis based on single fixations (i.e., using very small AOIs). Right part: Schematic illustration of EEG data segments aligned to larger AOIs which would be typically used in multimedia research. Longer EEG segments could be used without overlapping. Note. The EEG and eye-tracking data has been artificially combined and does not show data of a real person.

Another, however easily addressable challenge of overlapping EEG segments in fixation-related EEG data analysis are specific EEG correlates at the very beginning of a stimulus (e.g., when the text for reading is shown on the screen for the first time). To avoid stimulus-presentation associated event-related EEG correlates potentially masking fixation-related EEG correlates, the first 700 ms of stimulus presentation (i.e., the first few fixations) should be excluded from EEG data analysis (Dimigen et al., 2011).

Finally, defining an adequate baseline for EEG data analysis is not trivial in free viewing situations (Dimigen et al., 2011; Nikolaev et al., 2016). In classical EEG data analysis typically a pre-stimulus baseline is used for baseline correction in order to reduce slow currency drifts (e.g., due to fatigue) in the EEG epochs used for analysis (Picton, 2000). As in fixation-related EEG data analysis the pre-fixation baseline is contaminated by saccadic activity, it has been proposed to alternatively use a short time-frame directly after fixation-onset as baseline (e.g., Baccino, 2011) or to use a global, pre-stimulus baseline (i.e., a baseline at the beginning of the task; Nikolaev et al., 2016). To date, there is no clear recommendation of what time interval is best suited as baseline in fixation-related EEG data analysis. Choosing an adequate baseline may largely depend on the concrete task design. Potentially, in FRBP it might also be possible to report absolute power values (i.e., to avoid using a baseline) if the experimental conditions (i.e., the AOIs for which the EEG data is analyzed and compared) are fully permutated with respect to spatial and temporal positions (i.e., when spatial or timing issues can be excluded as potential confounds of the data).

5. Conclusions

Despite the remaining challenges of using the methodology of fixation-related EEG data analysis, the methodology clearly is at the frontline of learning research. EEG (alpha and theta) frequency band power may help gaining deeper insight in the cognitive processing of multimedia elements (i.e., text and picture and resulting CL or affective effects). Thus, FRBP may substantially contribute to a better understanding of multimedia design effects like pictorial seductive details and consequently may foster better instructional design.

Keypoints

- EEG alpha frequency band power allows assessing cognitive load (and potentially affective effects) during learning with multimedia task materials.
- The methodology of fixation-related frequency band power analysis (FRBP) allows studying the EEG frequency band power in free viewing situations.
- FRBP thus allows comparing cognitive load when different multimedia elements are fixated (e.g., text versus picture).
- The methodology may thus provide a deeper understanding of multimedia design effects like the pictorial seductive detail effect.

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