BRAIN'S CAPACITY TO DETECT ABSTRACT REGULARITIES FROM VISUAL STIMULI UNDER DIFFERENT ATTENTIVE CONDITIONS – AN ERP STUDY

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Masters' thesis

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Many previous studies have applied oddball paradigm to study change detection. Although changes within single features have been investigated a lot, the changes in multiple feature conjunctions have not. The aim of our study was to investigate with event-related potentials by applying oddball paradigm, whether the brain can detect abstract regularities in visual stimulus stream when two different features are combined - semantic meaning and color. Participants were shown adjective words written in red and blue print in quasi-random order on a computer screen. In an oddball paradigm, 90 % of the words ('standard') followed the rule "words printed in red have a negative meaning and the words printed in blue have a positive meaning". In the rest 10 % of the words ('deviant'), the rule was reversed: "words printed in red have a positive meaning and the words printed in blue have a negative meaning". In the half of the subjects the rules in standards and deviants were reversed. The effect of attention directed to the stimuli was explored by using two groups of subjects. In one group, the subjects were not informed of the regularities in stimuli (non informed, n=20), and they were instructed to count the six-letter words. In the other group participants were informed about the rule for the regularity and they were instructed to count the rule violations (informed, n=20). During the experiment, participants' electroencephalography (EEG) was recorded with electrodes attached to their scalp. In non informed group the deviants elicited differential ERPs (event-related potential) compared to standards at two different latencies. At 320-360 ms post-stimulus a negative shift was observed in posterior electrodes and a positive shift in fronto-central electrodes. At 410-450 ms post-stimulus a negative shift was observed in left temporal electrodes and a positive shift in right temporal electrodes. In the attended informed group no significant differences were found between standards and deviant responses at any latency range. The results are discussed in the context of the visual mismatch negativity (vMMN).

Keywords: visual word processing, visual mismatch negativity (vMMN), oddball paradigm, attention, semantics, feature integration

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Useat aikaisemmat tutkimukset ovat käyttäneet oddball paradigmaa tutkiakseen muutoksen havaitsemista. Vaikka muutoksia yksittäisissä piirteissä on tutkittu paljon, niin muutoksia piirreyhdistelmissä ei ole. Tutkimuksemme tarkoituksena oli selvittää herätevasteita mittaamalla ja soveltamalla oddball paradigmaa, pysyvätkö aivot havaitsemaan abstrakteja säännönmukaisuuksia visuaalisesta ärsykevirrasta, kun kaksi eri piirrettä on yhdistetty – semanttinen merkitys ja väri. Koehenkilöille näytettiin sinisellä ja punaisella kirjoitettuja adjektiivisanoja satunnaistetussa järjestyksessä tietokoneen ruudulle. Oddball paradigmassa 90 % esitetyistä sanoista (’toistettu ärsyke’) noudattivat sääntöä ”punaisilla kirjoitetuilla sanoilla on negatiivinen merkitys ja sinisillä kirjoitetuilla sanoilla on positiivinen merkitys”. Lopuissa 10 %:ssa esitetyissä sanoissa (‘poikkeava ärsyke’) sääntö oli toisin päin: ”punaisella kirjoitetuilla sanoilla on positiivinen merkitys ja sinisellä kirjoitetuilla sanoilla on negatiivinen merkitys”. Puolella koehenkilöistä säännöt toistetuissa ja poikkeavissa ärsykkeissä olivat käänteiset. Ärsykkeisiin suunnatun tarkkaavuuden vaikutusta tutkittiin käyttämällä kahta koehenkilöryhmää. Yhdelle koehenkilöryhmälle ei kerrottu ärsykkeissä esiintyvästä säännönmukaisuudesta (ei-informoidut, n=20) ja heitä pyydettiin laskemaan kuusikirjaimiset sanat. Toisessa ryhmässä koehenkilöille kerrottiin säännönmukaisuudesta ja heitä pyydettiin laskemaan säännönrikkovat sanat (informoidut, n=20). Kokeen aikana koehenkilöiden aivosähkökäyrää (EEG, elektroenkefalografia) mitattiin päänahkaan kiinnitetyillä elektrodeilla. Ei-informoidussa ryhmässä poikkeavat ärsykkeet saivat aikaan erilaiset herätevasteet (ERP, event-related potential) verrattuna toistettuihin ärsykkeisiin kahdella eri aikavälillä. 320-360 ms ärsykkeen esittämisen jälkeen negatiivinen erotusvaste havaittiin pääntakaosan elektrodeilla ja positiivinen erotusvaste edessä ja keskellä päätä sijaitsevilla elektrodeilla. 410-450 ms ärsykkeen esittämisen jälkeen negatiivinen erotusvaste havaittiin vasemmalla ohimolohkon alueella sijaitsevilla elektrodeilla ja positiivinen erotusvaste vastaavilla oikean puolen elektrodeilla. Suunnattua tarkkaavuutta edellyttävässä informoidussa ryhmässä merkitseviä eroja ei löytynyt toistettujen ja poikkeavien ärsykkeiden aiheuttavien vasteiden välillä millään aikavälillä. Tuloksia pohditaan visuaalisen poikkeavuusnegatiivisuuden (vMMN) kontekstissa.

Avainsanat: visuaalinen sanan prosessointi, visuaalinen poikkeavuusnegatiivisuus (vMMN), oddball paradigma, huomiokyky, semantiikka, piirteiden yhdistäminen

CONTENTS

1. INTRODUCTION

1.1. Role of visual attention in perception – automatic vs. conscious processing

Visual attention is an important cognition in getting information from the constantly changing external world around us. *Attention* includes the ability to select some information for more detailed inspection, while ignoring other information (Smith, Nolen-Hoeksema, Fredrickson, & Loftus, 2003). *Perception* includes the analysis of senses such as vision, audition, taste, olfaction and touch (Andrewes, 2001).

Visual attention directs cognitive capacity to a subset of available visual information, allowing the individual to quickly search through salient environmental stimuli, detect changes in their visual environment, and single out and acquire information which is relevant for the current task (Myers & Neth, 2007). Detecting changes in otherwise regular stimulus stream can be considered at least in some cases crucial for survival. The following features of visual attention are relevant regarding perception: (1) a limited capacity for processing information, (2) the selectivity - the ability to filter out unwanted information, and (3) integration - the combining of several object properties such as color, shape, orientation, and so on, “binding” (Desimone & Duncan, 1995).

One area of agreement in cognitive psychology is that certain types of behavior can be performed with little, if any, focused attention, whereas others are highly sensitive to the allocation of attention. *Automatic processes* direct behavior that occurs without conscious awareness and without producing interference with ongoing activities. *Conscious operations* differ fundamentally from automatic processing in that they require focused attention (Kolb & Whishaw, 2003). There is now fairly widespread agreement that perception can occur even when we are unaware that we are perceiving (Cohen & Schooler, 1997).

1.2. Automaticity of the visual word processing

Reading is an important everyday activity of literate people. Because of that many attempts have been made to understand the underlying processing mechanisms. One specific question of interest is whether humans' cognitive system can process words in the absence of the central attentional resources needed for carrying out many other higher cognitive functions, such as response selection and decision making (e.g. Johnston, McCann, & Remington, 1995).

Single-task studies have provided evidence for the automaticity of word reading. One example is the well-known *Stroop effect*, where response time is longer in naming the ink color of a word that spells an incongruent color name than a congruent color name (MacLeod, 1991). This finding suggests that word reading is automatic: people have massive difficulty in voluntarily suppressing the reading of a fully irrelevant word.

However, dual-task studies have gained different conclusions regarding the automaticity in visual word processing. Some have concluded that certain word processes (e.g., frequency-sensitive forms of lexical processing) were subject to postponement or could not take place while central attention is directed to another task (e.g., McCann, Remington, & Van Selst, 2000). Other studies have reached however the opposite conclusion (e.g., Cleland, Gaskell, Quinlan, & Tamminen, 2006). Allen, Cornett, Goodin, Lien and Ruthruff (2008) concluded in their dual-task study that visual word processing, e.g. lexical activation and semantic activation of the word, is not fully automatic but rather requires access to limited central attentional resources.

1.3. The feature integration theory of attention

Visual search is one of the dominant paradigms used for investigating visual attention (Shen, Reingold, & Pomplun, 2003). When taking into account how separate visual features are detected and combined as united perception in visual stimulus stream, Treisman and Gelade's (1980) *feature integration theory* (FIT) of attention is worthy of consideration. FIT brings light to the special role that attention plays in object detection. In the feature-integration theory of attention visual features of the object are detected early, automatically and in parallel while the objects are identified separately at the later stage of processing which requires focused attention. The authors assumed that the visual scene is initially coded along a number of separable dimensions, such as color, orientation, spatial frequency, brightness, etc. In order to ensure the correct synthesis of features for each object, stimulus locations are processed serially with focal attention. Any features which are present in same central “fixation” of attention are combined to form a single object (Treisman, 1977).

In a series of clever experiments Treisman and colleagues (1980) asked participants to identify a target item located in a visual field that was filled with nontarget items, distracters (e.g. single letter “T” hidden among five “S”s). Treisman found out that reaction time of the target in single feature search condition is small and constant regardless of the number of distracters. This phenomenon has since been identified as *perceptual pop-out*. Treisman argues that pop-out is preattentive. A *preattentive process* is one that happens automatically and effortlessly. In vision preattentive processes as part of the processing of an image happen very fast, usually within the first 100 ms. Pop-out happens also when the target and the distracters differ in color, motion, or brightness, suggesting that these dimensions constitute a basic set of visual features. In a single feature search condition, the distracters do not include the key feature which is present in target item. Instead in the conjunction search the features of the target item are also included in the distracters and the target item is distinguished only when the combination of these features are present. Therefore the search time is shorter in single feature search condition compared to search times for conjunction targets.

Despite the studies of Treisman and colleagues, the issues covered in the FIT have not gained support from all investigations. In Quinlan’s article (2003) he notes that there have been many studies that have reported examples of conjunction detection in the absence of attention (e.g. Houck & Hoffman, 1986).

To conclude the results of FIT, there is no consensus over the question whether attention has a special role in visual feature integration and what the role of the attention might be. Although changes within single features have been investigated a lot, the multiple feature conjunctions have not. This study will broaden the knowledge of brains change detection under different attentive conditions when two different features are combined –semantic meaning and color. I will return to this attention theme after few chapters when introducing first some basic concepts in relation to our study.

1.4. Event-related potentials and mismatch negativity

Event-related potentials (ERPs) are voltage fluctuations in *electroencephalography* (EEG) induced within the brain. ERPs directly measure the electrical response of the brain to sensory, affective, or cognitive events, and are induced by as a sum of a large number of action potentials. Typically they are generated as a response to external stimulation, and appear as somatosensory, visual, and auditory brain potentials, or as slowly evolving brain activity observed before voluntary movements. ERPs are quite small (1-30 µV) relative to the background electroencephalographic activity and, therefore, require the use of signal-averaging techniques for their elucidation. There are three main dimensions by which the ERP waveform can be characterized: *amplitude* (= an index of the extent of neural activity), *latency* (= timing of the neural activity), and *scalp distribution* (= the pattern of the voltage gradient of a component over the scalp at any time instant). The ERP signals are either positive, represented by the letter P (such as P300), or negative, represented by letter N (such as N400). The digits indicate the time in terms of milliseconds after the stimuli (Sanei & Chambers, 2007).

The mismatch negativity (MMN) is a negative component in the EEG curve, elicited by change in regularity in the stimulus stream (Pazo-Alvarez, Cadaveira, & Amenedo, 2003). MMN is the earliest ERP component induced within the brain that indicates brains capacity for change detection (Sanei & Chambers, 2007). Such a mechanism is important to enable attention to be switched to important changes in the environment. The MMN results from a comparison process between an incoming deviant stimulus and the representation of the standard stimulus in the sensory memory (Näätänen, Jacobsen, & Winkler, 2005).

1.4.1. Mismatch negativity in the visual modality

MMN was first found in the auditory modality (Näätänen, Gaillard, & Mäntysalo, 1978) and is thought to be generated in the primary auditory cortex (Kropotov et al., 2000). The auditory MMN component is a negative ERP which can be elicited when a sound violates some preattentively detected regularity of the auditory stimulus sequence (Näätänen, 1990; Näätänen & Alho, 1997). This negative ERP component peaks around 150-250 ms after the onset of deviant stimulation (Näätänen et al., 1978). This brains capacity to change detection is traditionally studied in *an oddball paradigm* in which often occurring standard stimuli are occasionally replaced by rarely occurring deviant stimuli differing from the standards in some physical feature (Pazo-Alvarez et al., 2003). The amplitude of the MMN is directly corresponding, and its latency inversely related, to the degree of difference between standard and deviant stimuli (Sanei & Chambers, 2007). *Auditory mismatch negativity* (aMMN) is elicited to several stimulus dimensions and even in the absence of attention (Näätänen et al., 1978). Therefore, it is relatively automatic (Sanei & Chambers, 2007). It has been for a long time unclear whether MMN occurs in other sensory modalities.

Several studies have tried to find whether there is a visual counterpart to the aMMN (e.g. Cammann, 1990; Csibra & Czigler, 1991; Heslenfeld, 2002). In other studies, the authors analyzed the ERPs which were evoked by visual deviant stimuli within broader experimental objectives (Alho, Woods, Algazi, & Näätänen, 1992; Berti & Schröger, 2001). Most of these studies reported visual *N2* (negative wave) -like components elicited by infrequent deviations in several stimulus dimensions such as color (Mazza, Turatto, & Sarlo, 2005), shape (Mazza et al., 2005), motion direction (Amenedo, Pazo-Alvarez, & Cadaveira, 2007), orientation (Astikainen, Ruusuvirta, Wikgren, & Korhonen, 2004; Astikainen, Lillstrang, & Ruusuvirta, 2008), spatial frequency (Heslenfeld, 2002), luminance (Stagg, Hindley, Tales, & Butler, 2004), size (Kimura, Katayama, & Murohashi, 2008), facial expressions (Astikainen & Hietanen, 2009), etc. These studies used variety of designs: visual discrimination studies; active, passive and delayed response oddball paradigms and intermodal selective attention studies (Pazo-Alvarez et al. 2003).

According to the review by Pazo-Alvarez et al. (2003), the component that seems to be the best candidate for possible MMN counterpart is an early negative one, which appears in the N2 latency range with a topographical distribution that is modality specific. *The visual mismatch negativity* (vMMN) is described as a negativity measured at the occipital electrodes between 150 and 350 ms after the onset of an infrequent (deviant) visual stimulus in a sequence of frequently presented (standard) visual stimuli. The vMMN is suggested to have similar properties as the aMMN. It can be evoked preattentively and it reflects the use of a memory representation of regularities in visual stimulation (Czigler, 2007). However, when considering the results of this review, it seems that there needs to be greater difference between standards and deviants to elicit MMN compared to aMMN. Heslenfeld (2002) obtained a good candidate for visual counterpart of the aMMN because he found an automatic component free of exogenous effects. There is still debate among researchers concerning what would be the best ERP component for vMMN. That is the reason why further investigation is needed, and our study is on its behalf trying to broaden the knowledge of possible vMMN in brains capacity to detect changes in abstract regularities.

1.4.2. Attention and mismatch negativity

Attention effects to MMN have mainly studied in auditory modality and debate whether attention modulates the MMN component of ERPs has lasted for over a decade (Sussman, 2007). Although it is broadly regarded that aMMN reflects a preattentive auditory process (e.g., Näätänen et al., 1978), many studies have shown that attention affects to the MMN (e.g., Alain & Woods, 1997; Arnott & Alain, 2002). Sussman (2007) represents in her study two different but interrelated processes, which are involved in MMN elicitation: regularity formation and deviance detection. The "standard" is needed for deviance detection and according to her studies these two systems are differentially affected by attention. Standard formation process is much more susceptible to attentional manipulation than deviance detection.

1.4.2.1. Attended versus ignored conditions

When investigating attention effects on MMN amplitude, one problem is faced. There are overlapping attentional components with MMN which makes it difficult to detect the MMN (Sussman, 2007). *N2b* component, which is a negative-going waveform, is one of these overlapping components. The *N2 complex* consists of two components: the *N2a* or MMN, which occurs whenever the brain detects an occasional deviant stimulus in a sequence of standard auditory stimuli, whether or not the auditory stimuli are task-relevant (Rugg & Coles, 1995), and the N2b which is evoked when infrequent stimulus is attentively detected as being different from a frequently repeating stimulus (Näätänen, Simpson, & Loveless, 1982). Therefore it often cannot be fully separated from the MMN and true amplitude of the MMN cannot be generally determined in attended conditions. This problem is not faced in unattended condition. There are very few studies that have compared MMN elicitation to an attended versus unattended in separate conditions to assess if the response amplitude is modulated by this factor. However, in those few studies of aMMN there were no significant difference in the amplitude of the MMN found when comparing the MMN elicited in an ignore condition to the same tones when attended (Sussman et al., 2004).

Obviously more research is needed also considering attention effects on MMN. In our study we have two different kinds of groups where the depth of attention to the target stimuli is modulated.

1.4.2.2. P3a and P3b components in MMN studies

Among others Sussman, Winkler, and Schröger (2003) found in their studies that MMN amplitude is also not affected by the expectation or previous knowledge that a deviant sound will occur. They found out that the opportunity to observe effects of expectation on MMN was available in a study designed to investigate effects of expectation on the *P3a* component. This fronto-centrally distributed positive potential peaking 300-400 ms after stimulus presentation has been described as a brain 'orienting' response to discrete novel event in human ERP studies (Barceló, Periáñez, & Knight, 2002). P3a has been reported for auditory, visual, and somatosensory stimuli (Courchesne, Hillyard, & Galambos, 1975; Courchesne, Kilman, Galambos, & Lincoln, 1984; Knight, 1984; Squires, Squires, & Hillyard, 1975). In the auditory modality the P3a indicates involuntary orienting to a salient or novel auditory stimulus. It is elicited without focused attention on the sounds and is thought to reflect the action which occurs in attention switching (Friedman, Cycowicz, & Gaeta, 2001).

Sussman et al. (2003) presented paired visual and auditory stimuli in predictable and unpredictable conditions. Expectation of the deviant had no significant effect on the MMN latency or amplitude even though the subsequent P3a component was abrogated by this information. In other words, knowing in advance that a deviant sound is about to occur eliminates an involuntary orienting response to the deviant but has not any effect on the stage of deviance detection which is reflected by MMN. That is, no P3a component was observed in the predictable condition, but instead *P3b*, which is ERP component occurring when attention is directed to target stimulus, was observed.

This more centro-parietal scalp localized P3b is also elicited by infrequently occurring events, but these events must typically be task-relevant, or involve a decision (typically by pressing the button or mentally counting), to evoke this component (Friedman et al. 2001; Polich, & Comerchero, 1998). Generally speaking the P300 component (including subcomponents P3a and P3b) peaks normally between 250-500 ms depending on stimulus modality, task conditions, subject age, etc (Polich, 2007). The peak latency of the P300 component in the ERP is expected to occur of about 300-350 ms for auditory stimuli and 350-450 ms for visual stimuli in normal young adults (Johnson, 1988; Picton, 1992).

One example of highly focused attention effects to the MMN is the Woldorff, Hackley, and Hillyard's (1991) study where they used a dichotic listening paradigm. Participants were instructed to listen to the sounds in one ear, ignore the other ear, and press the response key when they detected intensity deviants. The MMN amplitude elicited by intensity deviants presented to the ignored ear was significantly smaller than the MMN amplitude to the attended ear. This demonstrated the attention effect on the MMN. Näätänen et al. (1993) replicated this study but took also into consideration the N2b component which overlapped with MMN in attended condition by adding the ignored condition to the study. Näätänen et al. (1993) replicated the results for the intensity MMN, that is, smaller amplitude elicited in the unattended ear, there was no effect of attention on the amplitude of the frequency MMN. These studies propose that MMN is not completely attention-independent.

1.4.2.3. Attention effects and visual feature conjunctions in vMMN study

There are only few previous studies where multiple different features are combined to study change detection in ignored and attended conditions considering vMMN studies. One study is performed by Winkler, Czigler, Sussman, Horváth and Balázs (2005). In the visual part of their article they investigated whether violation of conjunction of grating pattern orientation and color would produce same kind of vMMN when attention to the task was modulated. The same kind of vMMN component was found in both ignored and attended conditions occurring at 120-160 ms latency range reflected by posterior electrodes. Elicitation of similar vMMN responses in two conditions support the notion that the formation of visual feature conjunctions does not require focused attention. So these results contradicts FIT introduced earlier. These results are only from one study, so further investigation is definitely needed.

1.5. An electrophysiological measure of word processing

One especially useful electrophysiological measure of word processing is the *N400*, a negative-going brain potential occurring around 400 ms after the onset of potentially meaningful stimuli (written on spoken stimuli, as words, pictures, and faces) (e.g. Kutas & Hillyard, 1984). The description of the N400 scalp distribution seems to differ according to the task. Elicited by semantic incongruities in sentences, the N400 is largest over the centro-parietal regions and slightly larger over the right hemisphere than over the left (Kutas & Hillyard, 1982; Kutas, Hillyard, & Gazzaniga, 1988; Johnson & Hamm, 2000). In contrast, when elicited by single words, the N400 has a more anterior distribution, with maxima over frontal or central sites (Bentin, 1987; Bentin, McCarthy, & Wood, 1985; McCarthy & Nobre, 1993) and larger amplitude over the left than over the right hemisphere (Nobre & McCarthy, 1994). Semantic information processing takes longer than most types of physical processing; therefore it has been argued that N400 might be delayed instance of the N2 (Pritchard, Shappell, & Brandt, 1991). This component is often called MMN because it occurs most strongly when a stimulus does not match the current context (e.g. Kutas & Hillyard, 1984). For example, when one sees the word TABLE, then word FLOWER (unrelated) would produce MMN (N400) but the word CHAIR (related) would not. A critical point is that the N400 provides a definitive indication that a person has actually identified the word and extracted its meaning (Kutas & Van Petten, 1988).

Several studies have tried to figure out possible attentional modulation of N400 effect. This attentional modulation of semantic processing has been widely studied with *semantic priming*. Priming means that there is increased accessibility or retrievability of information stored in memory which is produced by the prior presentation of relevant cues (Smith et al., 2003). Several studies have investigated the N400 effect in experimental paradigms in which subjects were instructed to attend other than semantic features of visually presented word pairs. The effects of attention on the visual N400 effects have also been studied in paradigms which the subjects were instructed to selectively attend only particular stimuli. Relander, Rämä and Kujala studied (2009) how the semantics of spoken language was processed when attention was directed to another modality, to the phonetics of spoken words, or to the semantics of the spoken words. N400 effect was found in all tasks which indicates that semantic priming occurs when spoken words are not actively attended. Other studies have indicated that when processing of word meaning is task-irrelevant, the N400 effect is smaller and more widespread/delayed in time (Hohlfeld & Sommer, 2005; Hohlfeld, Sangals, & Sommer, 2004; Bentin, Kutas, & Hillyard, 1993). However, results on the automaticity of semantic processing of written words have not been entirely consistent. In one study, the effect was only found when the word pairs were presented to the attended visual field (McCarthy & Nombre, 1993). In a study in which attention was directed to words written in particular color, the N400 effect was found when only the prime words were attended, but not when only target words or neither primes nor targets were attended (Kellenbach & Michie, 1996).

Our study takes previous studies one step further in combining semantic meaning and the color of the word in oddball design. These features do not have any natural connection between one another and this kind of feature combination has not been studied in vMMN studies before.

1.5.1. Processing of emotionally meaningful words

Stimuli that people regard as emotionally arousing obtain prioritized processing. Fast responses to these stimuli (e.g. fear-relevant material such as snakes or spiders) are considered to be biologically adaptive (e.g. Öhman & Mineka, 2001). That is because emotionally intense stimuli usually represent things that, if encountered in real life, would threaten one’s well being.

ERPs have been shown to be sensitive to the conscious affective perception of words (e.g. Cacioppo, Crites, Gardner, 1996), faces (e.g. Kayser et al., 1997) and pictures (e.g. Johnston, Miller, & Burleson, 1986). Additionally, there is now considerable psychological and physiological evidence suggesting that affective processing occurs without conscious awareness (e.g. LeDoux, 1995; Shevrin et al., 1992). Notably, the general notion that hemispheric lateralization is important in affective processing has continued to gain support from ERP paradigms (Cacioppo et al., 1996; Kayser et al., 1997).

When subjects read words that vary in their emotional significance the evoked brain potentials show a negative going wave from around 200 to 300 ms and is enhanced for pleasant and unpleasant compared to neutral words (Herbert, Junghofer, & Kissler, 2008). This effect has been demonstrated for adjectives that were matched for word length, word frequency or concreteness (Kissler, Herbert, Peyk, & Junghofer, 2007). Emotional words were associated with enhanced brain responses arising in predominantly left occipito-temporal areas. This increased posterior negativity has been suggested to emerge seemingly effortless and spontaneous, if not completely automatic, selective processing of emotionally significant words. Such results demonstrate that at least a primitive semantic classification of the words happens within the first 250 ms after word onset.

So far, ERP research on emotion-attention interactions in visual word processing has focused on the *late positive complex* (LPC) (Kissler, Herbert, Winkler, & Junghofer, 2009). LPC is a term used to describe late positivities, which are broad positive potentials (after about 500 ms) in response to emotionally arousing pictures peaking over parietal brain areas. Late positivities have generally been associated with task demands like attentional capture, evaluation, or memory coding (e.g. Dien, Spencer, & Donchin, 2004). Fischler and Bradley (2006) review many studies where task demands were manipulated when subjects processed words or simple phrases that varied in emotional content. They report enhanced fronto-central positivity between 300-600 ms after stimulus onset in response to both pleasant and unpleasant compared to neutral material, when subjects evaluate emotional content or perform other semantic tasks on the presented material. In Fischler and Bradley's studies (2006) LPC emotion effects occurred when attention was directed to stimulus content.

1.6. Objectives of the present study

Our study examines if Treisman and Gelade's (1980) perceptual pop-out phenomenon in feature integration theory can expand the knowledge of brain capacity to detect abstract or even semantic regularities from visual stimuli when semantic meaning and color are combined and if the depth of attention directed to visual stimuli affect detecting those regularities. According to Treisman and Gelade's FIT, the visual conjunction detection is not possible without focused attention but as introduced earlier many diverging results have been found, also when considering automaticity in visual word processing in dual-task studies.

Brain responses might be extremely sensitive to elicit preattentive processes. In our study, we wanted to take one step further and examine by recording brains EEG during visual word processing if the semantic word processes can take place automatically preattentively while central attention is devoted to another task. ERPs were generated by visually presented adjective words, which served as stimuli. It could be predicted, as in the vMMN study of Winkler et al. (2005), where violation of conjunction of grating pattern orientation and color produced same kind of vMMN in attended and ignored conditions, that vMMN components could be found in both conditions also in our study.

We investigated the next two issues by applying oddball paradigm: (1) do deviant stimuli (violation of semantic regularity combined with color) elicit differential ERPs compared to standard stimuli in participants brain; (2) whether there are differences in the processing of the violation of semantic regularity combined with color when altering the depth of attention directed to visual stimuli by using ignored and attended groups (P3a component is expected to occur in ignored group and P3b in attended group, possible appearance of vMMN and N400 components in both groups).

2. MATERIALS AND METHODS

2.1. Participants

Participants were recruited via websites department of Psychology of University of Jyväskylä, via e-mail post as well as from acquaintances of members of the research group. Forty (n=40) native Finnish speaking volunteers participated in the study; they were between 20-35 years of age (M= 25.6), 29 were female and 37 were right-handed. All of the participants reported having normal hearing and vision and vision was corrected if necessary. No one also had any diagnosed neurological disorders. Before participation subjects were informed of the study and signed informed consent was obtained from all of them. After EEG recordings, participants were given evaluation forms in order to find out how the participants interpreted word meanings (see Appendix 1: An evaluation form of adjectives). They were asked to evaluate every adjective which was used in experiments whether the meaning of the word was positive or negative. The study was approved by the ethical committee of the University of Jyväskylä and the experiment was undertaken in accordance with the Declaration of Helsinki.

2.2. Stimuli and procedure

Thirty Finnish adjective words written either on blue or red print served as stimuli and were presented on the computer screen. The words varied in emotional content: fifteen of the presented words (50 %) had a positive meaning, e.g. "HYVÄ" (good), and other fifteen words (50 %) had a negative meaning, e.g. "HUONO" (bad). The words were taken from frequency vocabulary of the Finnish newspaper language. This vocabulary was gathered by Center of Science Information Technology. These adjectives were collected from among ninety most used adjectives, length and a positive or negative emotional reaction as criteria (see Appendix 2: Stimulus material in Finnish and English). Stimuli words were shown in the middle of a computer screen one at a time. The words were presented either in color red or blue bolded capital letters in a Courier New font on a white background. Point size of the words was 30. One word was presented 250 ms on a screen, followed by 800 ms break with blank screen before presenting the next word.

An oddball paradigm was applied. In the first stimulus condition (figure 1) 90 % of the stimuli ('standards') followed the rules "the word written in red color includes a negative meaning" and "the word written in blue color includes a positive meaning". 10 % of the stimuli ('deviants') violated this rule, in other words, in those words the combinations were reversed.

OUTO	ILOINEN	PAHA	TURHA	RAJU	VARMA	HYVÄ	SAIRAS
ST.	ST.	ST	DEV.	ST.	ST.	ST.	ST.

FIGURE 1. An oddball paradigm: Stimulus condition 1

In the second stimulus condition (figure 2) these features were combined other way round: standards followed the rules "the word written in blue color includes a negative meaning and "the word written in red color includes a positive meaning" and deviants violated two possible way these rules.

OUTO	ILOINEN	PAHA	TURHA	RAJU	VARMA	HYVÄ	SAIRAS
ST.	ST.	ST.	DEV.	ST.	ST.	ST.	ST.

FIGURE 2. An oddball paradigm: Stimulus condition 2

Standards and deviants were shown in a quasi-randomized order: there were at least two standard stimuli presented between deviant stimuli. In both sessions there were 100 stimuli ('deviants') which violated the rule, so altogether 1000 stimuli. Duration of one session was approximately fifteen minutes.

Subjects were familiarized with the laboratory setting and EEG electrodes were attached. During recording, the participant was seated in a comfortable chair. A computer screen, with a visual angle of 6.2° × 8.6°, was placed in front of the participant and the participant was asked to target their gaze at cross in the middle of the screen on which the visual stimuli were displayed. The screen was placed approximately 1.0 m in front of the participant at eye level. A black cross in the middle of the screen was used as a fixation point. Participants were instructed to fixate to the middle of the screen and remain their fixation throughout the whole recording. Participants were also asked to be as relaxed as possible and avoid moving during the recording that unwanted activity (considered as artefacts) in EEG would be minimized. During the recordings, the subjects were observed via a video monitor.

2.3. Ignored and attended groups

We had two different groups, ignored and attended, in which the participants' depth of attention to the target stimuli was regulated by different instructions. Stimuli were the same for both groups. Throughout these experiments there was an intention to study if the focused attention was necessary for the brain to detect abstract regularities in visual stimuli, which were in this case semantic categories associated with color.

Possible preattentive processing of the violation of semantic category combined with color in visual word processing was studied with ignored group. In ignored group participated twenty (n=20) volunteers; they were between 20-35 years of age (M=25.9 years), 16 were female and 19 were right-handed. Stimulus conditions were counterbalanced between subjects so that half of the participants (n=10) went through stimulus condition one and the other half (n=10) went through stimulus condition two. The participants in ignored group were instructed to count all six-letter words. No information about semantic categories was given. The session duration was approximately fifteen minutes and in the middle of the session there was a little break for participant to relax because the task was quite demanding. During the break participants were asked to report how many six-letter words they had detected so far. After the break participants were instructed to start counting again from zero. Again after the whole recording the participants were asked to report the amount of the detected six-letter words after the break. In these stimulus conditions there were 350 six-letter words in each, on average 175 before the break and 175 after the break. After the recording participants were also asked if they perceived some sort of regularity in the way words were presented.

In attended group participated twenty (n=20) volunteers; they were between 21-34 years of age (M=25.3 years), 13 were female and 18 were right-handed. Stimulus conditions were counterbalanced between subjects as in ignored group. Participants were informed about the regularity of the semantic categories and that sometimes that regularity is violated. Participants were instructed to count all the words that violated the semantic regularity combined with color. Total of 100 semantic violations (‘deviants’) were presented.

2.4. EEG recording

Electroencephalography was recorded with Brain Vision Recorder software (Brain Products GmbH, Munich, Germany). The recording of the ERPs was conducted with 26 inserted electrodes (F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, P7, P8, Fz, Cz, Pz, FC1, FC2, Refr., FC5, FC6, Oz, CP1, CP2, CP5, CP6, EOG) using an electrode cap (Easy Cap). Recordings were conducted according to the international 10-20 system. Eye movements and blinks were recorded with two bipolar electrodes (EOG = electro-oculogram) placed one above the left eye and the other lateral to the right orbit. Ground electrode was placed in the middle of the forehead and an average reference was applied.

2.5. Data analysis

The data was analyzed with Brain Vision Analyzer software (Brain Products GmbH). First the data was filtered by using IIR (Infite Inpulse) -filters with a band pass of 0.1–30 Hz. Also notch filter was used. Next an artifact correction was carried out. EEG with more than -100 µV or 100 µV was considered to be contaminated (EEG being marked as bad 200 ms before and after the event) by ocular activity or muscular movements and thus was deleted. Then the segmentation of the EEG was carried out into 900 ms epochs (-100 ms - 800 ms) separately for deviant and standard stimuli. We took into analysis the data of those subjects with at least 50 trials (total amount 100 trials) accepted after the artifact rejection. On average, 76.0 % of both the standard and the deviant trials were included in to the analysis from the participants taken into analysis, the lowest percentages for an individual subject being 53 % of the standard trials and 56 % of the deviant ones. Data from eight participants had to be deleted (five from ignored and three from attended group) because of too large amount of artifacts in their EEG. If the impedances were above 20 kΩ in the beginning of recording, were those channels deleted. In addition from four different participants' data from one electrode had to be deleted from the analysis because of the artifacts (electrodes O2, C3, CP5 and P7). Next the remaining trials were baseline corrected against their average during a 100 ms prestimulus period. Finally, the trials were averaged into ERP waveforms, and grand averaged waveforms across all subjects were created.

Based on visual scrutiny of the grand averaged ERP waveforms four ERP peaks with noticeable positive or negative differences between waveforms evoked by standard and deviant stimuli were selected for further analysis (see results). The peak amplitudes of the deflections at 320-360 ms and 410-450 ms post-stimulus periods were measured in ignored group (group counting six-letter words) from every subject. Also in attended group (group counting words breaking the semantic regularity) the peak amplitudes of the deflections at 420-460 ms and 440-480 ms post-stimulus periods were measured from every subject. When analyzing different deflections at different time windows were following electrodes chosen for statistical analysis (see table 1 and 2). Latencies were not analyzed in this study but latency values are also shown in table 1 and 2 because peak amplitudes from different electrodes were taken from following peak latencies. The electrode sites were chosen after inspection of grand averaged event-related potential waveforms and previous literature. The peak ERP amplitude values were taken into SPSS for Windows program for further analysis.

TABLE 1. The mean peak latency (ms) of the 320-360 ms and 410-450 ms deflections of the event-related potentials in standard and deviant conditions from analyzed channels in ignored group (n=15). Values are expressed as means ± SD.

Ignored group					
320-360 ms			**410-450 ms**		
Electrode	Standard	Deviant	Electrode	Standard	Deviant
Fz	330.07±13.94	337.07±10.83	F3	431.73±18.77	434.60±15.61
F4	334.00±16.56	336.13±12.55	F4	424.47±14.51	424.20±18.29
FC6	335.00±15.33	340.71±16.40	F8	424.86±16.97	425.50±17.04
FC2	337.33±18.67	339.33±12.17	FC2	419.87±13.86	423.93±16.77
Cz	342.33±18.66	337.87±13.63	FC5	433.33±15.75	432.07±13.22
C4	340.60±17.85	338.13±15.72	FC6	433.07±17.11	419.64±16.07
CP2	341.67±17.77	337.93±16.45	C3	434.64±17.02	428.93±17.36
CP5	332.73±16.41	331.33±12.16	Cz	420.47±14.88	427.00±13.07
P7	329.87±15.14	332.73±11.98	C4	426.93±17.12	431.80±15.60
O1	338.33±17.01	335.80±14.27	CP2	426.67±16.65	434.80±15.38
Oz	336.27±16.79	336.13±14.11	CP5	432.27±15.11	428.67±15.74
			CP6	433.20±16.67	435.53±16.08
			P3	434.07±16.36	425.07±17.05
			P4	431.20±16.87	438.47±13.87
			P7	425.33±17.06	428.73±17.54
			O1	420.33±17.02	417.33±13.47

TABLE 2. The mean peak latency (ms) of the 420-460 ms and 440-480 ms deflections of the event-related potentials in standard and deviant conditions from analyzed channels in attended group (n=17). Values are expressed as means ± SD.

Attended group					
420-460 ms			**440-480 ms**		
Electrode	Standard	Deviant	Electrode	Standard	Deviant
Fz	430.35±14.98	436.24±14.68	Fz	462.41±17.79	456.00±17.40
F4	435.00±15.81	439.65±15.11	F4	460.24±17.91	456.12±15.58
FC1	437.82±14.36	437.65±13.11	FC1	459.00±17.95	449.88±13.22
FC2	437.47±17.28	445.41±14.10	FC2	459.76±17.88	456.18±13.87
C3	437.53±15.49	436.18±13.00	C3	465.82±15.67	454.76±16.92
CP2	434.65±17.77	429.88±13.77			
P4	432.47±16.24	427.29±11.16			
Pz	435.35±17.17	432.18±15.27			
P7	440.63±13.45	444.69±13.62			
P8	429.71±13.85	437.82±14.16			
O1	434.12±15.81	432.00±12.74			
Oz	432.00±15.32	427.71±11.39			
O2	433.69±16.39	430.69±12.15			

Statistical analyses were performed by SPSS for Windows program. In order to investigate whether standard and deviant responses differed from another the peak voltages of the four separate ERP peaks were analyzed using separate repeated-measures analyses of variance (two-way MANOVAs). The within subjects factors were: stimulus type (standard vs. deviant) x electrode. Paired samples t-tests were performed in order to further investigate the repeated measures MANOVA results whenever a significant main effect for the stimulus type or electrode was found or if a significant interaction between the stimulus type and electrode was found. Because of a too small amount of degrees of freedom, the positive and negative amplitudes considering one time window needed to be analyzed in different statistical models.

3. RESULTS

3.1. Behavioral results

In ignored group the correct answer for the number of target words (six-letter words) was 350. The amount of reported six-letter words ranged from 157 to 273 words. Participants detected an average of 63.2 % of the target words. When asked after the experiment, two of the participants noticed that there was some sort of regularity between color and meaning of the words but they were not able to describe it completely. In attended group the correct answer for the number of the target words (semantic regularity was violated) was 100. The amount of reported target words ranged from 37 to 77 words. Participants detected an average of 60.2 % of the words.

The adjective evaluation form results indicate that four participants from the ignored group evaluated some words differently as we had evaluated. 1.25 % of the negative adjective words were rated by participants as positive and 0.2 % of the positive adjective words were rated as negative. Words that were rated differently were: “VAIKEA” (hard), “RAJU” (rough), “OUTO” (strange), “HIENO” (fine).

3.2. Event-related potential results

3.2.1. Ignored group

3.2.1.1. 320-360 ms post-stimulus period

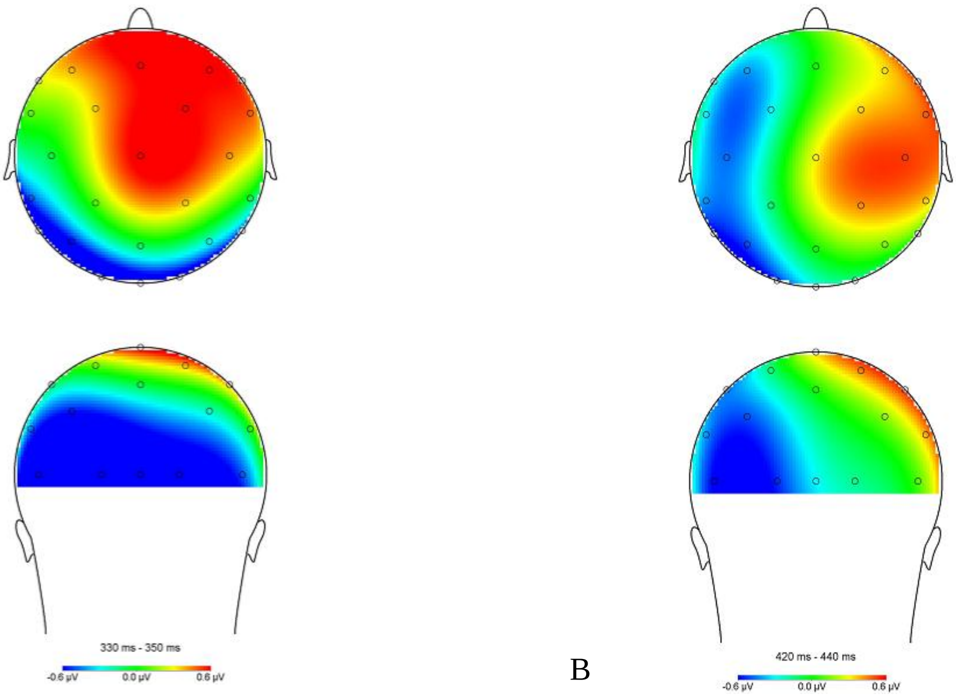
In order to investigate whether standards and deviants elicited different responses was separate repeated-measures analyses of variance (two-way MANOVAs) utilized. Paired samples t-tests were performed in order to further investigate the repeated measures MANOVA results. For the frontal electrodes (figure 3), the repeated measures 2 (stimulus type) x 7 (electrode) MANOVAs revealed a significant main effect for stimulus type ($F(1,13)=5.27$, $p=0.039$, $\eta^2=0.29$), and for electrode ($F(6,78)=4.72$, $p=0.024$, $\eta^2=0.78$) indicating that standards and deviants elicited different responses and values differed between electrodes. There were not any significant interaction effect between stimulus type and electrode. Paired samples t-test for the mean amplitudes between electrodes revealed a trend, (t=2.13, p=0.051), towards a significant difference between the standard -0.3408 µV and deviant responses 0.0024 µV.

For the occipital electrodes (figure 3), the repeated measures 2 (stimulus type) x 4 (electrode) MANOVAs revealed a significant main effect for stimulus type, ($F(1,14)$= 4.93, p=0.043, η^2=0.26), and for electrode, ($F(3,42)$=5.12, p=0.017, η^2=0.56), indicating that standards and deviants elicited different responses and values differed between electrodes. There were not any significant interaction between stimulus type and electrode. Paired samples t-test for the mean amplitude between electrodes revealed statistically significant difference to the standard 0.2855 µV and deviant responses -0.2144 µV, (t=-2.22, p=0.043).

3.2.1.2. 410-450 ms post-stimulus period

The repeated measures 2 (stimulus type) x 7 (electrode) MANOVAs revealed a significant main effect for the stimulus type for the left temporal electrodes (figure 3), ($F(1,13)$=14.69, p=0.002, η^2=0.53), indicating that standards and deviants elicited different responses. There were not any significant interaction between stimulus type and electrode and either any other main effects were not significant. Paired samples t-test for the mean amplitudes between electrodes revealed a trend, (t=-2.15, p=0.050), towards a significant difference between the standard 0.0318 µV and deviant responses -0.2685 µV.

The repeated measures 2 (stimulus type) x 9 (electrode) MANOVAs revealed a significant main effect for the stimulus type for the right temporal electrodes (figure 4), ($F(1,12)$=7.33, p=0.019, η^2=0.38), indicating that standards and deviants elicited different responses. There were not any significant interaction between stimulus type and electrode and either any other main effects were not significant. Paired samples t-test for the mean amplitude between electrodes revealed statistically significant difference to the standard –0.1082 µV and deviant responses 0.2508 µV, (t=2.94, p=0.011). From table 3 can be seen grand average mean peak amplitude values for differential ERPs for analyzed electrodes and time windows in ignored group. From figure 4 can be seen the grand-averaged ERP waveforms to standard and deviant stimuli from all electrodes in ignored group.



A B

FIGURE 3. The scalp potential maps at 330-350 ms (A) and 420-440 ms (B) post-stimulus illustrate the differential ERPs (deviant-standard) marked with the red and blue color in ignored group (n=15). The scale in ERP amplitudes range from -0.6µV to 0.6 µV. Please note that the figures show brain activity shorter period of time than used in analysis to search peak amplitude values.

TABLE 3. Grand average mean peak amplitudes (µV) for differential ERPs (deviant-standard) for analyzed electrodes at 320-360 ms and 410-450 ms post-stimulus period in ignored group (n=15). Values are expressed as means ± SD.

Ignored group							
320-360 ms				**410-450 ms**			
Electrodes with positive amplitude values		Electrodes with negative amplitude values		Electrodes with positive amplitude values		Electrodes with negative amplitude values	
Electrode	Mean amplitude	Electrode	Mean amplitude	Electrode	Mean amplitude	Electrode	Mean amplitude
Fz	0.51±1.24	CP5	-0.39±0.59	F4	0.65±1.18	F3	-0.08±1.03
F4	0.56±1.35	P7	-0.47±1.06	F8	0.33±1.24	FC5	-0.15±0.82
Cz	0.31±0.91	O1	-0.68±1.20	FC2	0.50±0.71	C3	-0.41±0.83
C4	0.24±0.83	Oz	-0.47±1.37	FC6	0.35±1.05	CP5	-0.34±0.57
CP2	0.20±0.86			Cz	0.37±0.62	P3	-0.35±0.86
FC6	0.24±1.19			C4	0.35±0.90	P7	-0.43±1.16
FC2	0.37±0.92			CP2	0.36±0.82	O1	-0.45±1.48
				CP6	0.18±0.66		
				P4	0.15±0.94		

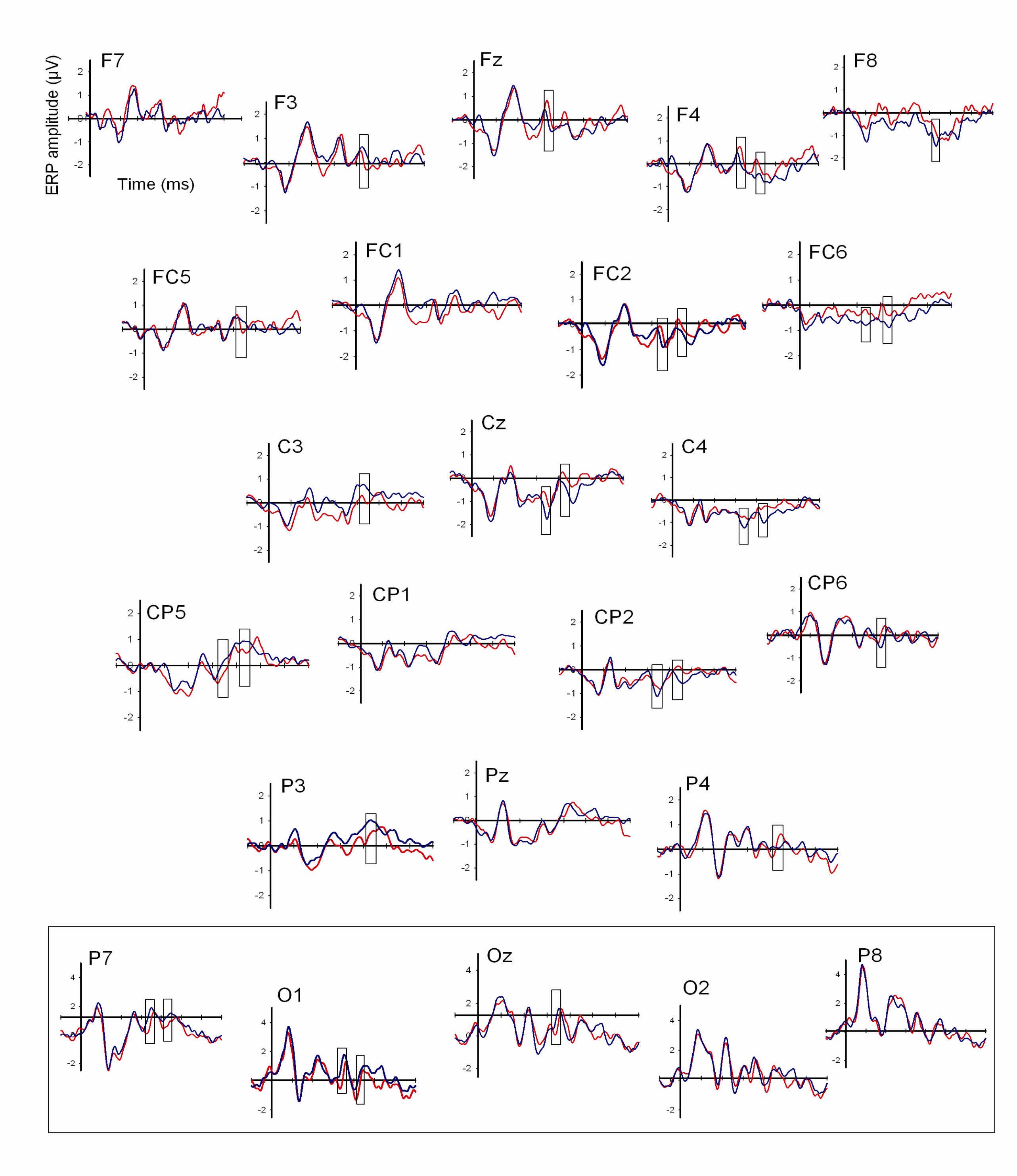


FIGURE 4. The grand-averaged ERP waveforms to standard and deviant stimuli from all electrodes in ignored group (n=15). Time periods at 320-360 ms and 410-450 ms, where peak values from every subject were searched, are marked with rectangles. The maximum amplitude value from every subject was taken into analysis. On the x-axis is the time relative to the stimulus onset in milliseconds divided into 100 ms periods. On the y-axis are the potentials in microvolts. The potentials for standard stimuli are indicated with blue lines and the potentials for deviant stimuli, with red lines. Different scaling is used for channels P7, O1, Oz, O2 and P8.

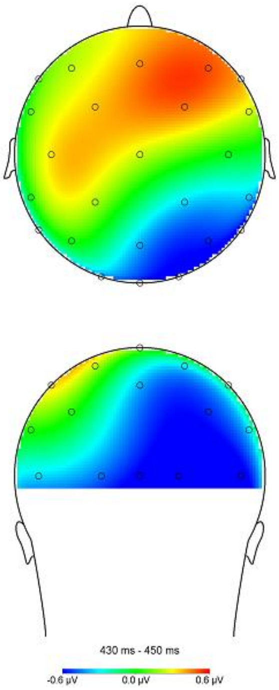
3.2.2. Attended group

3.2.2.1. 420-460 ms post-stimulus period

The repeated measures 2 (stimulus type) x 5 (electrode) MANOVAs did not reveal any significant interaction between stimulus type and electrode and either none of the main effects were significant in frontal electrodes (figure 5). The repeated measures 2 (stimulus type) x 8 (electrode) MANOVAs did not reveal any significant effects in posterior electrodes either.

3.2.2.2. 440-480 ms post-stimulus period

The repeated measures 2 (stimulus type) x 5 (electrode) MANOVAs did not reveal any significant interaction between stimulus type and electrode and either none of the main effects were significant in centro-parietal electrodes (figure 5). From table 4 can be seen grand average mean peak amplitude values for differential ERPs for analyzed electrodes and time windows in attended group. From figure 6 can be seen the grand-averaged ERP waveforms to standard and deviant stimuli from all electrodes in attended group.



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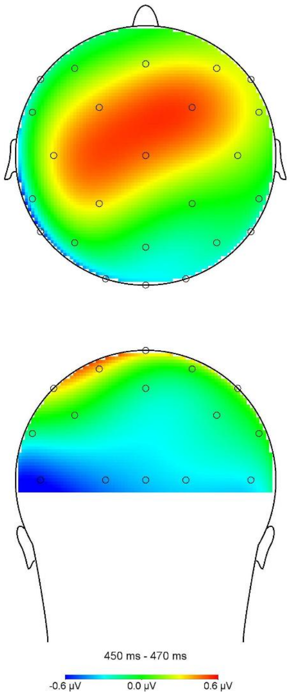

B

FIGURE 5. The scalp potential maps at 430-450 ms (A) and 450-470 ms (B) post-stimulus illustrate the differential ERPs (deviant-standard) marked with the red and blue color in attended group (n=17). The scale in ERP amplitudes range from -0.6 µV to 0.6 µV. Please note that the figures show brain activity shorter period of time than used in analysis to search peak amplitude values.

TABLE 4. Grand average mean amplitudes (µV) for differential ERPs (deviant-standard) for analyzed electrodes at 420-460 ms and 440-480 ms post-stimulus period in attended group (n=17). Values are expressed as means ± SD.

Attended group					
420-460 ms				**440-480 ms**	
Electrodes with positive amplitude values		Electrodes with negative amplitude values		Electrodes with positive amplitude values	
Electrode	Mean amplitude	Electrode	Mean amplitude	Electrode	Mean amplitude
Fz	0.13±1.15	CP2	-0.23±1.23	Fz	0.09±1.22
F4	0.24±1.01	P4	-0.33±0.96	F4	0.11±1.13
FC1	0.05±0.86	Pz	-0.36±1.31	FC1	0.01±0.86
FC2	0.22±1.06	P7	-0.02±1.18	FC2	0.31±1.03
C3	0.10±0.76	P8	-0.26±1.16	C3	0.03±0.84
		O1	-0.19±1.05		
		Oz	-0.29±1.14		
		O2	-0.49±1.39		

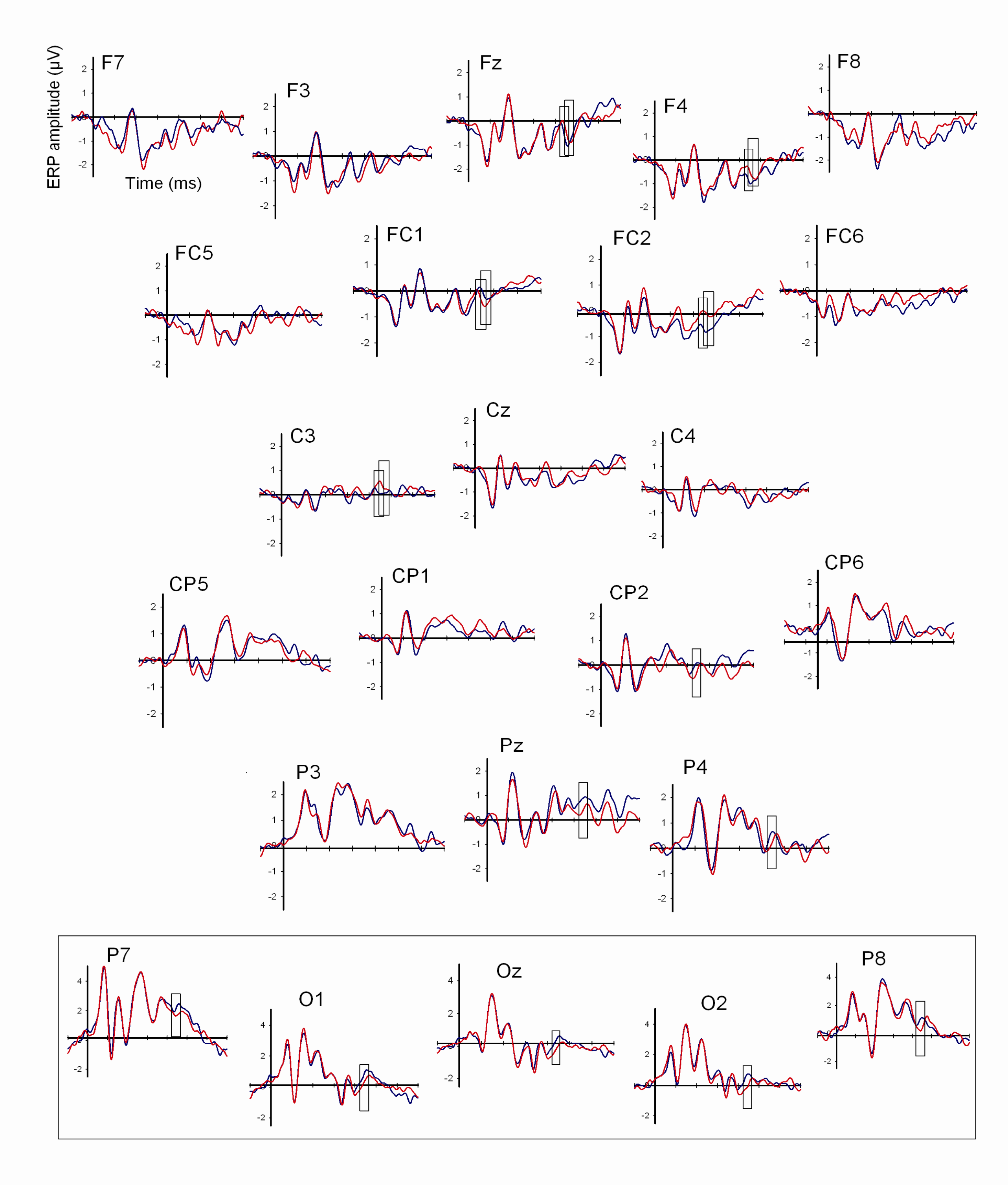

FIGURE 6. The grand-averaged ERP waveforms to standard and deviant stimuli from all electrodes in attended group (n=17). Time periods at 420-460 ms and 440-480 ms, where peak values from every subject were searched, are marked with rectangles. The maximum amplitude value from every subject was taken into analysis. On the x-axis is the time relative to the stimulus onset in milliseconds divided into 100 ms periods. On the y-axis are the potentials in microvolts. The potentials for standard stimuli are indicated with blue lines and the potentials for deviant stimuli, with red lines. Different scaling is used for channels P7, O1, Oz, O2 and P8.

4. DISCUSSION

The aim of this study was to establish whether brain can detect abstract regularities in visual stimulus stream reflected by possible vMMN and P3 components when two different features are combined - semantic meaning and color. We also wanted to investigate whether there are differences in the processing the violation of semantic regularity combined with color when altering the depth of attention directed to visual stimuli by using ignored and attended groups.

In the ignored group the deviants elicited differential ERPs compared to standards at two different latencies (see figure 3). At 320-360 ms post-stimulus a negative shift was observed in posterior electrodes and a positive shift in fronto-central electrodes (however, this was only a trend towards a significant difference, p=0.051). A similar trend, p=0.050, was observed at 410-450 ms post-stimulus as a negative shift in left temporal electrodes and a positive shift in right temporal electrodes was also found. In the attended group no significant differences were found between standards and deviant responses at any latency range. Because the found p-values are extremely close to statistical significance, it would be too strong assumption to conclude that deviant stimuli are not processed differently in participants' brain compared to standards. However, these results are more complex than the single MMN expected especially because there were not any statistically significant differences in attended group.

The posterior negativity at the latency of 320-360 ms may correspond to vMMN. This is supported by the experimental condition applied (oddball paradigm), scalp distribution (mainly occipital), polarity (a negative difference between ERPs to deviants compared to standards), and probably also the latency range of the deflection found. Considering the latency of the vMMN, most of the studies have reported it occurring before 200 ms (Pazo-Alvarez et al., 2003) but some data have suggested later latencies for the vMMN (i.e. 210-400 ms) (e.g. Tales, Newton, Troscianko, & Butler, 1999; Stagg et al., 2004). For example in color vMMN studies the latency of vMMN has ranged between 120 and 350 ms (Pazo-Alvarez et al., 2003). One problem is however faced. Semantic information processing generally takes longer than the processing of physical stimulus features (Pritchard et al., 1991). It is shown in literature that considering emotional words at least primitive semantic classification of the words happens within the first 250 ms after word onset (Kissler et al., 2007) but more deeply the semantic meaning of the word is processed not until 400 ms post-stimulus in attended conditions (e.g. Kutas & Hillyard, 1984). Preattentive processing occurs however much earlier than conscious processing, so it might be possible to brain detect semantic regularity violation at 320-360 ms latency range. Could it be possible that there are two negative peaks that would both reflect vMMN?

This serial processing hypothesis is supported by double MMN investigations. Wang, Cui, Wang, Tian and Zhang (2004) found negative potential with two peaks, N270 and N400, when attending to the conjunction of color and shape mismatches. Even though the classical N400 component is elicited in response to the processing of semantic incongruous words (Kutas & Hillyard, 1980), N400 has also been elicited by nonword stimuli (Bentin & McCarthy, 1994; Eimer, 2000). Wang et al. (2004) suggest that the two serial negativities in response to attended feature conjunctions might reflect the temporal different stages for processing conjunction mismatches or conflicts. Double mismatch was also found by Wang et al. (2003) in their multi-feature conflict study.

In addition to posterior negative difference ERPs, we found also an anterior positivity to deviants relative to standards at 320-360 ms post-stimulus. This may correspond to P3a. It has been described in literature as a brain ‘orienting’ response to discrete novel event in human ERP studies (Barceló et al., 2002), and could have been expected in ignored group. It means in our study that the deviant stimuli could have directed participants’ attention while they were counting the six letter words. The latency range 320-360 ms, polarity and also this fronto-central scalp distribution is what has been reported at in the literature for P3a component (Barceló et al., 2002). It is elicited without focused attention so it does not matter that only two of the participants reported noticing some sort of regularity in word stimulus stream (Friedman et al., 2001).

The left temporal negativity at the latency of 410-450 ms may also partly correspond to vMMN. The latency, polarity and parietal component is in analogy to prior findings in literature for N400 (Bentin, 1987; Bentin et al., 1985; McCarthy & Nobre, 1993; Nobre & McCarthy, 1994). It has been argued that N400 might be delayed instance of the N2 (=MMN) (Pritchard et al., 1991). Could it be possible that N400 like component is the vMMN? Astikainen and Hietanen (2009) speculated a similar issue in their vMMN study of facial expressions that face specific N170 component could be the vMMN. But it is obvious that the relationship between the vMMN and N400 must be clarified in future studies. If in our study there is a double MMN suggested by Wang et al. (2004), then the N400 could be the result of processing multiple mismatches or complex conflicts more deeply. Maybe deeper processing of semantic meaning combined with color need more time to be processed in the brain. For the support this view Rebai, Bernard and Lannou (1996) performed a study in relation to the Stroop test. They found out that the N400 component emerged only for the mental naming of a color when it was associated to the written name of another color. So, also in this study the semantic meaning conflicted with the color, similarly as it was with the deviants in our study.

It is known in literature that the description of the N400 scalp distribution seems to differ according to the task. Elicited by single words, which were used as stimuli in our study, the N400 has a more anterior distribution, with maxima over frontal or central sites (Bentin, 1987; Bentin et al., 1985; McCarthy & Nobre, 1993) and larger amplitude over the left than over the right hemisphere (Nobre & McCarthy, 1994). Even though we used single words as stimuli the activation is not shown quite similarly as in previous findings. On the other hand the scalp distribution of possible N400 (as being also the vMMN) may emerge in this manner. However, further investigation is definitely needed to clarify the relationship between activations observed.

What could the positive right temporal scalp distribution at 410–450 ms post-stimulus period possibly mean? The N400 component is rarely reported as dipole as it is shown in our study. Few exception results are found for example from Johnson and Hamm's study (2000) where they found along with centro-parietal N400 also P400 located in inferior to the temporal lobes. They used incongruous sentence endings as stimuli. However, Johnson and colleagues used 128 electrodes in their study and P400 was observed at non-standard recording locations which make it unlikely that we would reach same kind of results with 26 electrodes. Because there are no previous reported studies of processing of the combinations of word semantics and color, it could be that this cognition elicits a distribution which is not similar to N400 or traditional vMMN seen before.

So, what could be the reasons that there were not any statistically significant results in the attended group which were originally expected to at least to be found? The task was indeed very difficult but it does not explain why in ignored group where the word counting task was equally difficult, the results were found. In attended group it is also possible that some components are temporally overlapping with another and that is the reason why any statistically significant results are not found at any latency range. The negative deflection at 420-460 ms post-stimulus period could be interpreted as N400 by its latency and polarity. When there was no N400 in ERPs proved statistically significant in attended group, a low-amplitude centro-parietal negative deflection at 420-460 ms post-stimulus period could be interpreted as N400 (=vMMN). However the scalp topography does not support the definition of N400 because of the right frontal positivity. This amplitude deflection could be interpreted as the N400 beginning to rise, but being eclipsed by the rising part of the P3b. Indeed, both effects occur in approximately the same time regions and may overlap. As being also one of our hypothesis this low amplitude positive centro-parietal deflection at 440-480 ms latency range could well be the P3b because it is elicited when attention is directed to target stimulus (Sussman et al. 2003). This centro-parietal scalp localized P3b is elicited by infrequently occurring events, but these events must typically be task-relevant, or involve a decision (typically by pressing the button or mentally counting), to evoke this component (Friedman et al., 2001; Polich & Comerchero, 1998).

These N400 like deflections at 410-450 ms and 420-460 ms post-stimulus period between ignored and attended groups are not scalp distributed in a same manner. In both groups there are these negative and positive dipoles but the dipoles are differently localized between conditions (see figure 3 and 5). Relander et al. (2009) found in their semantic priming study that latency of N400 was the same in attended and ignored conditions. Although the N400 had a centroparietal maximum in the attended tasks, it was largest at the parietal recording sites in the ignored task. In our study the stimuli were the same for both groups, so it could be expected that only attention effects should give cause to these different scalp distributions.

When considering behavioral results between different groups, it seems that the word counting task was equally difficult for both groups. In ignored group only 63.2 % of the target words were found and in attended group only 60.2 %. This shows that the task was highly demanding for the subjects. Because the behavioral tasks were equally difficult, this could not have affected to the different results between groups. Performance levels showed that it was difficult to identify the target under the stimulus conditions of the present experiment, probably because both the stimulus durations and the interstimulus interval were short.

When considering performing further research involving this type of design, next issues would be good to take under consideration. At first it would be reasonable to study semantic and color violations separately to see how those results relate to our multiple feature violation results. In this study were used only healthy young adults as participants which makes the generalization of results to broader population more difficult. Also there were larger amount of women in this study than men (29 women, 11 men). This kind of design should be utilized also to children and elderly with equal amount men and women to investigate whether these kinds of results begin to be repeated or not. Also because the behavioral tasks of the design were highly demanding for the participants, perhaps some sort of modifications to design could be considered (e.g. by downsizing the amount of different adjectives presented on the screen and perhaps extracting the duration of the words presented on the screen or/and extracting the interstimulus interval duration). Maybe later on these results and further investigation results could be applied to some mental disorders to figure out possible information processing differences in change detection in feature conjunction situations.

What is also good to remember is the reliability of EEG method in localizing the activation. EEG gives an approximation about which part of the brain generates the activity, so that is the reason why dipoles found in our study should be considered with caution.

The fact that the visual feature conjunctions are processed in the absence of attention indicates that the model of a preattentive feature analysis and an attentive integration of these features proposed by the FIT, does not apply to this kind of visual processing. Consequently, the results of the current study strongly suggest that more research on preattentive visual feature binding needs to be carried out.

5. CONCLUSION

ERP amplitude differences between standard and deviant responses in ignored group indicated preattentive change detection at two different latencies. At 320-360 ms post-stimulus a negative shift was observed in posterior electrodes and a positive shift in fronto-central electrodes. At 410-450 ms post-stimulus a negative shift was observed in left temporal electrodes and a positive shift in right temporal electrodes. These results might indicate that brain can detect abstract regularities when two different features are combined –semantic meaning and color, even though the attention is directed away from those abstract regularities. In the attended group no significant differences were found between standards and deviant responses at any latency range perhaps due to temporally overlapping components with possible vMMN.

Negative deflections at 320-360 ms and/or 410-450 ms latency range might be the best candidate(s) to reflect possible vMMN in our design. These are interesting findings which are partly in line with the results of previous studies. Prior studies of vMMN have shown that at least in attended condition vMMN should be found which was not found in our study. Further investigation definitely is needed to solve the possible vMMN appearance in this kind of design. For now it remains an open question.

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APPENDIX 1: An evaluation form of adjectives

Olkaa hyvä ja arvioikaa rastittamalla oikea vaihtoehto ovatko alla olevat adjektiivit merkitykseltään positiivisia (+) vai negatiivisia (-):

	+	-
VAARALLINEN		
MAHDOTON		
HEIKKO		
HUONO		
KIPEÄ		
TURHA		
TURVALLINEN		
VÄÄRÄ		
RAJU		
OUTO		
PAHA		
HAUSKA		
TÖRKEÄ		
VAIKEA		
REILU		
HIENO		
SAIRAS		

	+	-
MAHDOLLINEN		
ILOINEN		
JÄRKEVÄ		
TERVE		
KAUNIS		
MUKAVA		
HANKALA		
UPEA		
KUOLLUT		
VARMA		
HYVÄ		
SELVÄ		
VAHVA		

Päivämäärä:

Koehenkilönumero:

APPENDIX 2: Stimulus material in Finnish and English

Words with positive meaning	Words with negative meaning
MAHDOLLINEN (possible)	VAARALLINEN (dangerous)
TURVALLINEN (safe)	MAHDOTON (impossible)
ILOINEN (glad)	KUOLLUT (dead)
JÄRKEVÄ (reasonable)	HANKALA (difficult)
VAHVA (strong)	HEIKKO (weak)
SELVÄ (clear)	HUONO (bad)
VARMA (sure)	KIPEÄ (hurt)
REILU (fair)	TURHA (futile)
HIENO (fine)	VÄÄRÄ (wrong)
TERVE (healthy)	RAJU (rough)
UPEA (amazing)	OUTO (strange)
HYVÄ (good)	PAHA (evil)
BEAUTIFUL (kaunis)	TÖRKEÄ (base)
MUKAVA (nice)	VAIKEA (hard)
HAUSKA (funny)	SAIRAS (sick)