Cognitive Neurodynamics
https://doi.org/10.1007/s11571-019-09544-x

RESEARCH ARTICLE

Measurement of cognitive dynamics during video watching through event-related potentials (ERPs) and oscillations (EROs)

Emel Erdogdu[1,2] · Elif Kurt[2,3] · Adil Deniz Duru[4] · Atilla Uslu[5] · Canan Başar-Eroğlu[1,6] · Tamer Demiralp[2,5]

Received: 19 November 2018 / Revised: 15 May 2019 / Accepted: 11 June 2019
© Springer Nature B.V. 2019

Abstract

Event-related potentials (ERPs) and oscillations (EROs) are reliable measures of cognition, but they require time-locked electroencephalographic (EEG) data to repetitive triggers that are not available in continuous sensory input streams. However, such real-life-like stimulation by videos or virtual-reality environments may serve as powerful means of creating specific cognitive or affective states and help to investigate dysfunctions in psychiatric and neurological disorders more efficiently. This study aims to develop a method to generate ERPs and EROs during watching videos. Repeated luminance changes were introduced on short video segments, while EEGs of 10 subjects were recorded. The ERP/EROs time-locked to these distortions were analyzed in time and time–frequency domains and tested for their cognitive significance through a long term memory test that included frames from the watched videos. For each subject, ERPs and EROs corresponding to video segments of recalled images with 25% shortest and 25% longest reaction times were compared. ERPs produced by transient luminance changes displayed statistically significant fluctuations both in time and time–frequency domains. Statistical analyses showed that a positivity around 450 ms, a negativity around 500 ms and delta and theta EROs correlated with memory performance. Few studies mixed video streams with simultaneous ERP/ERO experiments with discrete task-relevant or passively presented auditory or somatosensory stimuli, while the present study, by obtaining ERPs and EROs to task-irrelevant events in the same sensory modality as that of the continuous sensory input, produces minimal interference with the main focus of attention on the video stream.

Keywords Event-related potentials · Event-related oscillations · Cognitive dynamics · Wavelet transform · Continous sensory input

---

✉ Tamer Demiralp
demiralp@istanbul.edu.tr

Emel Erdogdu
emellerdogdu@gmail.com

Elif Kurt
elifkurt@istanbul.edu.tr

Adil Deniz Duru
deniz.duru@marmara.edu.tr

Atilla Uslu
auslu@istanbul.edu.tr

Canan Başar-Eroğlu
cbasar@uni-bremen.de; canan.basar@ieu.edu.tr

[1] Institute of Psychology and Cognition Research, University of Bremen, 28359 Bremen, Germany

[2] Hulusi Behçet Life Sciences Research Laboratory, Istanbul University, 34093 Çapa, Istanbul, Turkey

[3] Aziz Sancar Institute of Experimental Medicine, Department of Neuroscience, Istanbul University, 34093 Çapa, Istanbul, Turkey

[4] Department of Physical Education and Sports Teaching, Faculty of Sport Sciences, Marmara University, 34815 Beykoz, Istanbul, Turkey

[5] Department of Physiology, Istanbul Faculty of Medicine, Istanbul University, 34093 Çapa, Istanbul, Turkey

[6] Department of Psychology, Faculty of Arts and Sciences, Izmir University of Economics, 35330 Balçova, Izmir, Turkey

Published online: 20 June 2019

Introduction

Event-Related Potentials (ERPs) are recorded by presenting repeated discrete stimuli along the EEG recording and averaging epochs time-locked to these events, which made the ERPs precise and sensitive measures of the cognitive processes (Lang et al. 1997; Polich 2007). While ERPs can be characterized by amplitudes and latencies of the main wave components in the time domain, it has been shown that these wave components represent summed-up time-varying neural activation patterns of various neural circuits (Basar-Eroglu et al. 1992). To differentiate such parallel processes underlying the ERP generation, the time scales or frequency ranges of oscillatory signals and recognition and decomposition of spatial patterns may be important starting points (Basar et al. 1999; Demiralp et al. 2001; Ergen et al. 2012). Within this context, the neural oscillations recorded at various scales of nervous system organization have revealed important information about specific brain functions and behaviors (Basar and Bullock 1992; Bayram et al. 2011). Analysis of the oscillatory dynamics of the ERP signal, referred to as event-related oscillations (EROs), therefore contributed to a better understanding of the simultaneous involvement of various brain networks in brain functions (Basar et al. 2001; Kirmizi-Alsan et al. 2006; Demiralp et al. 2007; Selimbeyoglu et al. 2012; Ergen et al. 2014; Bayram et al. 2016) and helped significantly to gain fundamental knowledge on the pathophysiological processes underlying various neuropsychiatric conditions (Ergen et al. 2008; Güntekin et al. 2008; Basar et al. 2013; Basar-Eroglu et al. 2013). For estimation of the EROs with optimal time–frequency resolution the wavelet transform (WT) has been widely used (Grossman and Morlet 1984; Ademoglu et al. 1998; Basar et al. 1999; Demiralp and Ademoglu 2001; Herrmann et al. 2005).

On the other hand, due to the need of repeatedly presenting static stimuli, ERPs and EROs can hardly represent the cognition in the real-life, as the cognitive and especially affective processes depend strongly on the dynamic context of the experience. Hence, simulating continuous changes in the physical environment through audio-visual stimulus streams (for example videos) that better represent real-life conditions are important tools for reliable testing of cognitive and affective dynamics. Such real-life-like stimulation by videos or virtual-reality environments may serve as powerful means of creating specific cognitive or affective states and help to investigate dysfunctions in neuropsychiatric disorders more efficiently.

Creating an experimental design with sensitive measures of cognition such as ERPs but resembling more real-life conditions is an important step forward for optimizing experiments of cognition and emotion. There are a limited number of studies, which mixed video streams with simultaneous ERP designs by applying discrete auditory or somatosensory stimuli while viewing a video (Shigemitsu et al. 2007; Shigemitsu and Nittono 2008; Suzuki et al. 2005; Carvalho et al. 2011). In these studies, the stimuli applied in a different sensory modality were made task-relevant to obtain clear ERPs, and the subjects had to divide the attention to both visual and auditory or somatosensory modalities to fulfill the task. To overcome this problem, some studies applied task-irrelevant auditory or somatosensory probes and demonstrated that the ERPs to task-irrelevant stimuli in another sensory modality were sensitive to the allocation of subjects' attention directed towards the video (Kramer et al. 1995; Ullsperger et al. 2001; Allison and Polich 2008; Sugimoto and Katayama 2013; Roy et al. 2016; Takeda and Kimura 2014).

In the present study, we applied task-irrelevant stimuli in the same modality of the main sensory stream to produce ERPs similar to those obtained with the passive single-stimulus paradigm (Mertens and Polich 1997). Mertens and Polich (1997) conclusively demonstrated that the repeated presentation of a target stimulus in both passive (ignore) and active (mental or manual response) task conditions can elicit P300 responses in the participants comparable to P300 potentials to target stimuli in the classic oddball paradigm. Motivated by the passive single-stimulus paradigm, we introduced transient changes in the luminance of the videos. The hypothesis is that such slight changes in the video quality will produce significant time-locked P3-like responses, which would decrease their amplitudes with increasing attention directed to the content of the video (Allison and Polich 2008; Escera et al. 2000). Assuming that the level of the attention would correlate with the success in memorizing frames from the video, a long-term memory task (LTM), with either image frames from the viewed videos or distracting frames from other videos, was applied. By relating the response accuracy and reaction times to the target pictures with the ERPs/EROs obtained in response to distortions in the related parts of the videos, we tested which ERP/ERO features were modulated with the changing level of engagement and attention the subjects directed to the video content.

Methods

All participants gave written informed consent after the aim of the study and the data collection procedures were fully explained to them.

Participants

A total of ten (5 male, 5 female) right-handed Turkish student volunteers (mean age 25.5 ± 3.0 years) consented to participate in the study. All participants were in good physical health and none of them were taking any medication that might affect the ERP components.

ERP recordings

The EEG was recorded in an electrically shielded, sound-attenuated and dimly illuminated room. The EEG signal was collected using Ag/AgCl ring electrodes mounted in an elastic cap (EasyCap, Herrsching, Germany) from 30 channels (Fp1, Fp2, F3, Fz, F4, F7, F8, FC3, FCz, FC4, FT7, FT8, C3, Cz, C4, T7, T8, CP3, CPz, CP4, TP7, TP8, P3, Pz, P4, P7, P8, O1, Oz, O2). Electro-oculogram (EOG) was recorded bipolarly from electrodes placed at the outer canthus of the right eye and nasion. All EEG activity was referenced to linked earlobes. Electrode impedances were kept below 10 kΩ. EEG and EOG were amplified by BrainAmp DC amplifier (Brain Products, Germany) with a band pass filter of 0.1–70 Hz and digitized with a sampling rate of 1000 Hz. Stimulus presentation was carried out using the Psychophysics Toolbox (Brainard 1997) in MATLAB (The MathWorks, Inc., Mass., USA) environment.

Stimuli, video-selection and experimental design

In order to create transient ERPs/EROs, a luminance change was applied to the video-frames with a duration of 4 frames corresponding to 160 ms by increasing the RGB values of each pixel by 50 with a mean inter stimulus interval (ISI) of 3 s (randomized between 2 and 4 s).

The participants viewed four short videos with the total length of 11:25 min. The duration of each video varied from 0:52 min up to 4:50 min and they were separated with intervals of 5 s (Fig. 1). The videos were displayed on an LCD computer screen in an area of 15 cm height and 25 cm width (380 × 670 pixels). The refresh rate of the display was 75 Hz and the frame rate of the video clips was 25 Hz.

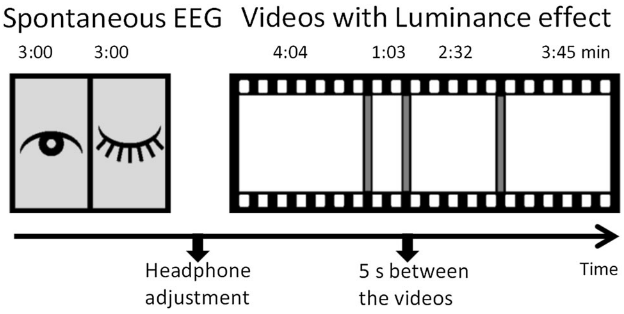

Fig. 1 Schematic view of the experiment schedule

The video pool was initially collected from various sources in the internet with special emphasis given to dynamic changes in the story such that a high variance in the engagement of the subjects to the video content can be expected. For this, 12 videos were viewed by 6 laboratory members to vote for 4 videos with most contrasting changes in the story matter.

After recording a spontaneous EEG with open and closed eyes for 3 min each, the subjects were asked to watch the set of videos attentively. Before the experiment the subjects were informed about a memory test that will be applied 30 min after the video session. They were also told that some luminance changes of the displayed videos might occur from time to time.

Long term memory (LTM) tasks

In order to test whether the ERP waveforms obtained during watching the videos correlated with the cognitive performance of the subjects, an LTM test was applied approximately 30 min after the EEG recording, in which either picture frames from the viewed videos (50% targets) or unseen pictures (50% distractors) from videos with similar properties were randomly presented on the computer screen. The targets were chosen from the viewed videos with approximately 20 s intervals. Total number of the targets was 35 for the duration of a set of 4 videos lasting 11:25 min. Recalled pictures had to be indicated as quick as possible by a left button press and non-recalled pictures by a right button press.

ERP data analysis

EEG artifact correction

For the elimination of artifacts in the EEG a three-stage procedure has been applied in the BrainVision Analyzer 2.2 software (Brain Products, Germany). In the first stage, EEG segments between 200 ms before and after parts with a voltage gradient higher than 50 µV/ms were automatically marked to avoid the misleading effects of fast muscle artifacts in the following step. In the second stage, the Independent Component Analysis (ICA) was applied to remove eye artifacts. In the final stage, a semi-automatic artifact rejection procedure was applied by rejecting parts of the data with voltages exceeding a maximum voltage difference of 200 µV within an interval of 200 ms and voltages lower than 0.5 µV within an interval length of 100 ms automatically, followed by a manual inspection of any remaining artifacts.

ERP computation

The ERPs were obtained by computing the ensemble average of artifact-free epochs between 0.2 s before and 1.3 s after the video distortions (the stimuli) using Matlab R2007 (The MathWorks, Inc., Mass., USA) scripts. Baseline correction was performed by subtracting the mean voltage between − 0.2 to 0 s from the averaged ERP.

To test the consistency of the ERP waveforms evoked by the transient luminance changes among the participants, we first performed one-sample *t*-test across the subjects for each time-point of the average signal from the 12 main fronto-occipital channels (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, O1, Oz, O2). Segments consisting of consecutive time points with $|t| > 1.833$ ($df = 9$, $p < 0.05$) were used to define the on- and off-sets of significant wave components for final analyses on separate channels by using the repeated-measures ANOVA design as described in "Statistical analyses" section. The significance of the ANOVA intercept factor reflected the significance of the mean amplitude of each wave component from the baseline.

Relation of ERPs and memory-test-derived performance data

Each video distortion has been associated with the target picture that was closest in time. By this way, each event was associated with a single specific video frame used in the LTM task, while a specific picture could correspond to more than one associated video distortion.

The performance of each subject was quantified on the basis of the reaction times after excluding the images with missed or false negative responses. To search for any relationship between the ERP waveforms and the LTM performance, the RTs to the target images in the LTM task were sorted for each subject and the ERP sub-averages corresponding to target images with 25% shortest and longest RTs were computed. Each sub-average of each subject consisted of approximately 48 single trials. The mean amplitudes of the ERP sub-averages for short and long RTs were calculated for the significant wave components as defined by the analysis in "ERP computation" section, and statistically compared as described in "Statistical analyses" section.

Time–frequency analysis of event-related-oscillations (ERO) using wavelet analysis

In order to compare the time–frequency characteristics of ERPs during more and less attentive periods, wavelet transform based on Morlet wavelet has been applied on each sub-average. Complex Morlet wavelet as described by Herrmann et al. (2005) was used as mother wavelet, which consists of a sinusoidal oscillation windowed in time by a Gaussian envelope. Frequency ranges of interest were defined based on the visual selection of the peak frequencies in the grand average time–frequency plots of the short and long RT trials (Fig. 4) (Table 2). The time courses of the magnitudes of the specified frequencies or frequency ranges were extracted from the time–frequency matrices of each subjects with a temporal resolution of 10 ms. For frequency ranges consisting of more than one frequency bin, these time courses were averaged over selected frequencies. Paired t-test was applied on the time courses of short and long RT conditions in order to find out the time windows that consisted of consecutive time points with $|t| > 1.833$ that corresponds to $p < 0.05$ for the $df = 9$. The average magnitudes for these time windows were then tested by repeated measures ANOVA design as described in "Statistical analyses" section.

Statistical analyses

Paired *t*-test is applied to verify the presence of a statistical difference between the 25% shortest and longest RTs. All statistical analyses on ERP/ERO data were carried out on the 12 main electrodes (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, O1, Oz, O2) split into two within-subject factors, antero-posterior locations (4 level: frontal, central, parietal and occipital) and lateral locations (3 levels: left, midline and right) in SPSS 21.0 (IBM Corp., Armonk, NY, USA). While the significance of the wave components was tested using the ANOVA intercept factor, the within-subject factor condition (2 levels: short vs. long RT) was added in the ANOVA design for statistical testing of mean amplitude differences between ERPs/EROs of short and long RT conditions. Greenhouse–Geisser corrected p values are reported.

Results

Averaged ERPs

The transient luminance-increases in the video produced clearly identifiable ERPs (Fig. 2). The preliminary analyses carried out by one-sample *t*-test on the average of 12 main fronto-occipital EEG channels revealed four time windows between 400–470, 500–550, 590–620 and 660–730 ms with consecutive time points deviating significantly from the baseline. These time windows nicely correspond to the 4 visually identifiable peaks in the averages over the channels. A repeated-measures ANOVA design with the antero-posterior and lateral location factors was carried out to test the topographic consistency of these peaks across the channels by using the mean amplitudes of these time

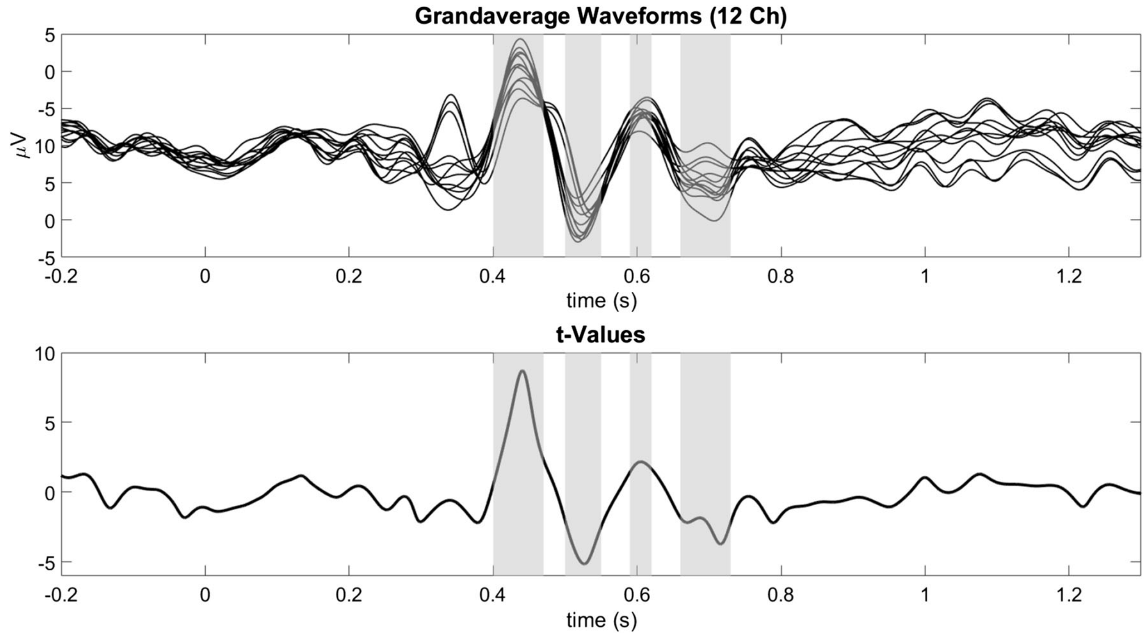

Fig. 2 Grand averages of the ERPs in 12 channels (N = 10) obtained by transient luminance changes in the videos (upper row) and the *t* values obtained by the one-sample *t*-test applied on the averages over these 12 channels across the subjects to define the time windows in which the waveform significantly deviates from the baseline. The grey shaded areas correspond to time windows consisting of consecutive time points with $|t| > 1.833$ ($df = 9$, $p < 0.05$)

windows in separate channels. The intercept factor of this ANOVA design confirmed that 3 out of these 4 waves, the positive wave between 400 and 470 ms and the negative waves between 500 and 550 ms and between 660 and 730 ms significantly deviated from the baseline, while the positive wave between 590 and 620 ms did not. The related F, *p* and partial eta^2 values are shown in Table 1. While the first 2 of these 3 waves showed a homogenous distribution across the channels with no significant antero-posterior or lateral location effects, the last negative wave displayed a significant change along the antero-posterior line with a maximum at central leads ($F_{3,27} = 4.21$; $p = 0.05$).

Table 1 Repeated-measures ANOVA tests based on 12 main electrodes at 4 antero-posterior (frontal, central, parietal and occipital) and 3 lateral (left, midline and right) positions for the mean amplitudes of the 4 ERP waves in the corresponding time windows

ERP waves	Time window (ms)	*F*	*p*	Part. eta^2
P450	400–470	41.863	< 0.001	0.823
N500	500–550	32.536	< 0.001	0.783
P600	590–620	3.750	0.085	0.294
N700	660–730	7.826	0.021	0.465

Time windows, F, *p* and effect sizes (partial eta^2 values) are shown for each wave component

Behavioral results: memory test (LTM)

The pictures presented during the LTM test were either known from the previous video set or unknown distractors. In total, 35 target and 35 distractor images were presented.

All subjects showed good memory performance (94 ± 4.4%) with only few false negative responses (not remembered video frames from watched videos) (6 ± 4.4%). The groups mean RTs to all correct responses of all subjects was 1069 ± 494 ms, while paired *t*-test statistics revealed a significant difference between the mean RT of 25% of shortest (688 ± 63 ms) and longest (1621 ± 420 ms) RTs ($p < 0.001$).

Averaged ERP and ERO: relation to the performance data of the LTM

Short versus long RT ERPs

To identify most prominent ERP properties reflecting the subjects' directed attention towards the video content, the averages of 25% of ERP trials corresponding to shortest (688 ± 63 ms) and longest RTs (1621 ± 420 ms) were calculated (Fig. 3). Mean and standard deviation of the number of trials included in short and long RT ERPs were 54.5 ± 3.92 and 53.7 ± 6.65, respectively, and did not differ significantly between the two conditions ($p = 0.72$). The comparison of the two grand average signals showed

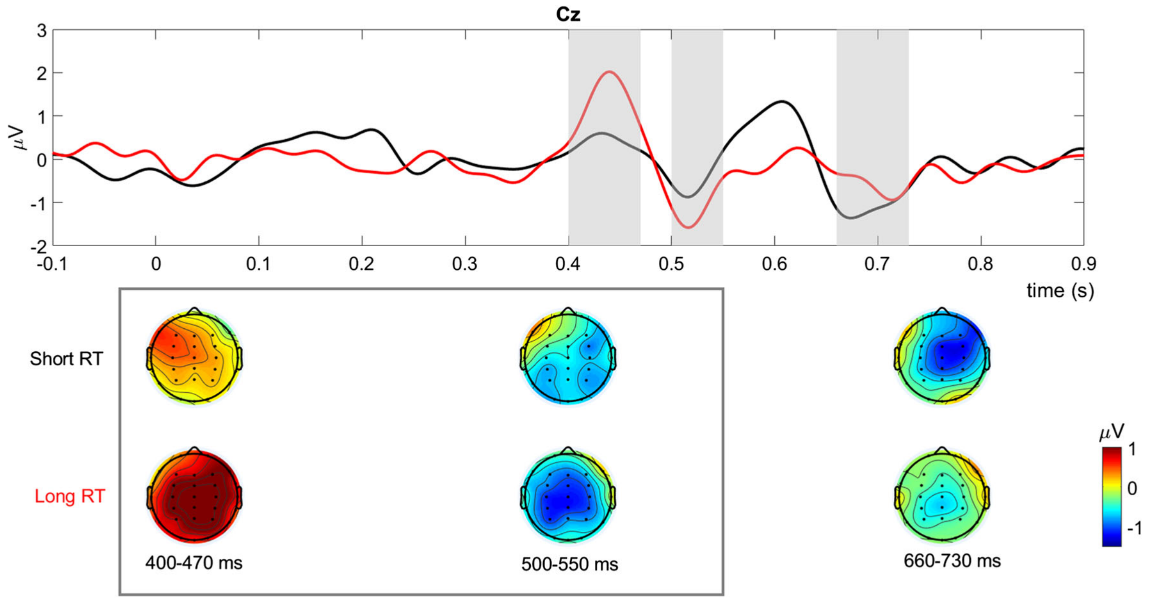

Fig. 3 Grand average ERPs related to 25% short (black line) and 25% long RT (red line) and topographies of the mean amplitudes of the 3 ERP wave components defined according to the *t*-tests applied on overall ERP averages: P450: 400–470 ms, N500: 500–550 ms and N700: 660–730 ms. Repeated measure ANOVA tests carried out on mean amplitudes of the shaded time windows revealed significant effects of the RT on the P450 and N500 components. (Color figure online)

distinguishable amplitude differences between the short and long RT conditions for the peaks as defined in the first subheading of the results section (Average ERPs) for the overall averaged ERPs. Mean amplitudes of the time windows corresponding to significant wave components (Table 1) were tested for significant differences between the short and long RT conditions by a repeated-measures ANOVA design with the within-subject factors condition, antero-posterior localization and lateral localization.

Statistical analyzes revealed a significant *RT* × *lateralization* effect for P450 on fronto-parietal region with higher amplitudes for long RT-ERPs at all electrodes, while a small positive residue was obtained in the short RT condition ($F_{2,18} = 4.581$, $p = 0.039$). A significant *RT* × *lateralization* effect was obtained for N500 at fronto-central electrodes with higher amplitudes and a central maximum for long RTs ($F_{2,18} = 4.197$, $p = 0.049$), while the overall amplitudes were smaller for the short RT condition with a small positive amplitude appearing on the left frontal region ($F_{2,18} = 4.197$, $p = 0.049$). There was no significant difference between the short and long RT ERPs for the N700 amplitude (Table 2).

Short versus long RT EROs

The grand average time–frequency plots of the ERPs related with 25% of shortest and longest RT trials (Fig. 4) displayed strong magnitude differences in the low delta (2 Hz), high delta (3–4 Hz) and theta (5–7 Hz) frequency bands. In order to define the time windows, in which these frequency ranges mostly differed between the short and long RT trials, the time courses of these frequency ranges with 10 ms temporal resolution were computed for the channels, in which they were most strongly expressed and compared by a paired t-test between the short and long RT conditions. This preliminary analysis revealed that consecutive time points in a low delta time window between 900 and 1270 ms, a high delta time window between 170 and 560 ms and a theta time window between 620 and 800 ms differed between the short and long RT conditions in frontal, parietal and central channels respectively. The average magnitudes for these time windows were then tested by repeated measures ANOVA design with condition, antero-posterior location and lateral location factors.

While the low delta activity (2 Hz) was almost absent in the short RT condition, a strong mid-frontal response (2 Hz) appeared in the long RT condition in the 900–1270 ms time window (RT: $F_{1,9} = 5.906$, $p = 0.038$), and the high delta (3–4 Hz) magnitude between 170 and 560 ms was also significantly stronger in long RT condition in centro-parietal region (RT: $F_{1,9} = 6.423$; $p = 0.032$). In contrary direction, the theta oscillations between 5 and 7 Hz revealed significantly stronger magnitudes for the 620–800 ms interval in the short compared to long RT condition ($F_{1,9} = 6.421$, $p = 0.032$).

Table 2 The ERP wave components and ERO frequency components, their time windows, topographic regions, ANOVA factors with significant effects and corresponding F and *p* values

ERP-component	Time (ms)	Regions	Factor	Effect	$F_{2,18}$	*p*
P450	400–470	Fronto-Parietal	Con × Lat	Short < Long	4.581	0.039
N500	500–550	Fronto-Central	Con × Lat	Short < Long	4.197	0.049
N700	660–730	–	–	–	–	NS
ERO-frequency	Time (ms)	Regions	Factor	Effect	$F_{1,9}$	*p*
Low Delta (2 Hz)	900–1270	Frontal	Con	Short < Long	5.906	0.038
High Delta (3–4 Hz)	170–560	Centro-Parietal	Con	Short < Long	6.423	0.032
Theta (5–7 Hz)	620–800	Fronto-Parietal	Con	Short > Long	6.421	0.032

Con condition, *Lat* lateralization, *NS* non-significant

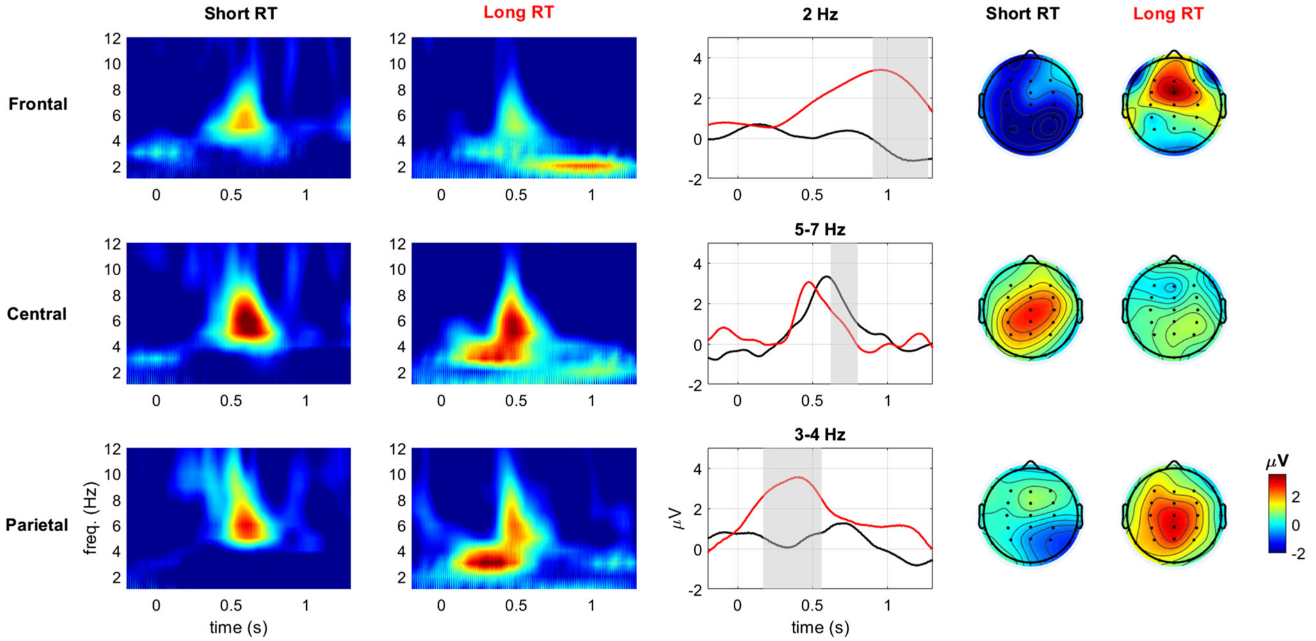

Fig. 4 Grand average time–frequency plots of the ERPs related with 25% shortest and longest RTs (first two columns), the time courses of the peaking frequencies (third column), the time windows of consecutive time points with significant difference between the two conditions according to preliminary paired *t*-tests for frontal, central and parietal channels (shaded areas on the third column): low delta (2 Hz, 900–1270 ms), theta (5–7 Hz, 620–800 ms), high delta (3–4 Hz, 170–560 ms). The topographies of the mean magnitudes of these time–frequency ranges with significant differences between the short and long RT conditions according to the final repeated measures ANOVA test are displayed in the fourth column. (Color figure online)

Discussion

As humans gain a huge part of information on their environment by vision and they have to behave in a dynamically changing environment, it is important to investigate the cognitive mechanisms of the human brain in experimental conditions that are closer to real world scenarios compared to the presentation of isolated transient stimuli to produce time-locked ERPs and EROs that are powerful signals to investigate cognitive mechanisms of the brain. In this study, we showed that clear ERPs and EROs can be generated time-locked to transient luminance changes introduced in video clips that do not disturb the overall visual experience but are long enough (160 ms) to create conscious sensory perception (Fig. 2). This result is important, since similar approaches adopted in earlier studies, that however are based on active tasks or task-irrelevant probes in another sensory modality have a higher probability to distract the subjects from the main channel of sensory input (Kramer et al. 1995; Ullsperger et al. 2001; Shigemitsu et al. 2007; Allison and Polich 2008; Liu et al. 2010; Carvalho et al. 2011; Sugimoto and Katayama 2013; Takeda and Kimura 2014; Roy et al. 2016). We claim that with the presented approach more realistic experimental designs can be produced, in which both continuous visual streams and transient visual events are optimally combined, such that the changing cognitive state of the viewer can be measured by means of widely investigated and statistically powerful methodology of ERPs and EROs.

In order to confirm that the obtained ERPs/EROs with the present approach are cognitively meaningful signals, we applied a long-term memory (LTM) test 30 min after presenting the videos. The LTM test presenting images from the viewed videos in addition to unviewed distractors resulted in only a small number of incorrect responses, which supports that the memory performance of the subjects was not significantly affected by the short luminance changes. However, due to the changing engagement of the subjects to the video content at different times, the reaction times to target images of the LTM test showed a clear intra-subject variability, which allowed us to identify the ERP/ERO components related to the engagement and directed attention of the subjects to the video content. The ERPs/EROs obtained by averaging single trials temporally closest to the images, which yielded 25% shortest and longest RTs in the LTM test, showed significant differences in the mean amplitudes of specific time windows and time–frequency regions.

A fronto-parietally distributed positivity between 400 and 470 ms (P450) followed by a fronto-centrally distributed negativity between 500 and 550 ms (N500) were associated with worse memory performance (Fig. 3). The wavelet analysis revealed significantly stronger delta power in the 170–560 ms and 900–1270 ms time windows in the long RT condition, where the earlier one at 3–4 Hz roughly corresponded to the P450 wave topography and probably reflected the same process, while the later one at 2 Hz with its long duration and clearly bounded midline frontal topography may be a starting point to create a useful electrophysiological feature of low attention periods in the ongoing EEG. The time–frequency analysis further showed that the theta response (5–7 Hz) between 620 and 800 ms is associated with better memory encoding leading to shorter RTs in the LTM task.

The topography of P450 in the present study showed a widespread positivity across fronto-parietal recording sites in the long RT condition resembling the topographical pattern of a P3-like wave obtained with the single-stimulus paradigm that has also been applied as a passive paradigm in earlier studies (Mertens and Polich 1997), in a similar manner as the presentation of short luminance changes in the present study. Functionally, the single-stimulus elicited P3 mimics the target P3 potential obtained in the classical oddball paradigm (Polich 2007) that displays the attention allocation for target stimulus processing in the active single-stimulus paradigm. It has also been shown that the obtained P3 in the ignore condition of the single-stimulus paradigm is of significantly larger amplitude compared to the P3 in the passive oddball condition (Mertens and Polich 1997).

By assuming that the P450 in the present study represents the P3-like wave of the passive single-stimulus paradigm, we interpret present findings in the following way: If the subjects' selective attention is focused to the content of the video, the distraction due to transient changes introduced in the video quality is not strong enough to produce a clear P3, while stronger P3 responses are obtained when the subject's attention is less engaged towards the video content leading to worse memory performance in the LTM task. Therefore, more resources are available during such periods of video watching to detect the transient video distortions. The stronger N500 in the ERPs during worse memory encoding periods may represent an after-effect of this preceding large P3-like positivity, as both waves share the similar topographic pattern of a wide fronto-parietal extent with symmetrical distribution.

On the other hand, the statistical results showed that the reaction times significantly interacted with the laterality of the amplitude differences for both P450 and N500 waves, which seems to depend on the presence of a left frontal positivity for both time windows in ERPs to events around better memorized video frames (Fig. 3, upper topographies within the grey frame). This topographical pattern may reflect the previously documented role of the left prefrontal cortex in encoding of episodic information (Tulving et al. 1994; Nessler et al. 2006).

The stronger early delta response may represent the time–frequency counterpart of both P450 and N500 waves in the time domain, while theta oscillations in the 620–800 ms time period were stronger in EROs to events that are close to better recalled video frames as shown by shorter RTs in LTM task. The importance of EEG theta oscillations during memory encoding periods has been reported in a number of studies (Klimesch 1999; Sauseng et al. 2004; Backus et al. 2016; Scholz et al. 2017). Within this context, the increased theta oscillation may reflect higher attention directed towards the video content and better memory encoding as a result.

While video streams were used for various purposes in ERP studies, such as diverting the conscious attention away from the auditory stimuli in mismatch negativity (MMN) studies (McArthur et al. 2003), there are also some examples of their use for creating visual real-world like events by specifically produced short video clips such as those to create N400 potentials through an inappropriate ending (Sitnikova et al. 2003, 2008). However, there are only few studies, which similar to the present work, tried to produce ERPs to reflect a participant's level of engagement during an ongoing visual or audiovisual experience (Allison and Polich 2008; Suzuki et al. 2005; Shigemitsu et al.

2007; Shigemitsu and Nittono 2008; Carvalho et al. 2011). Suzuki et al. (2005) and Carvalho et al. (2011) applied an auditory oddball task during video presentation and reported that the auditory targets produced significantly smaller P3b potentials when the subject was more engaged in the video content. The main disadvantage of these types of studies is that the active target detection task also introduces a significant distraction of the subject from the video content. To overcome this problem, Shigemitsu and Nittono (2008) produced ERPs with a simple reaction time (SRT) task and obtained smaller N140 responses to the somatosensory stimuli applied during time periods as the subject was more engaged in the video. Although the task is easier compared with the target detection, the subjects' attention is still divided between the audio-visual material and the somatosensory stimuli.

In contrast to the above summarized studies, the present study showed that passive stimulation condition with slight intermittent visual distortions in the video clip can produce significant ERPs that might further be used to measure the engagement of the subject to the video content. Such setup based on video streams gives the possibility to create more realistic and effective stimulation conditions by means of video contents that may reveal specific aspects of cognitive and affective dysfunctions in psychiatric and neurological disorders more efficiently. Especially, the use of the recently developed virtual-reality type task environments in detecting cognitive dysfunctions (Tarnanas et al. 2014) points to the importance of the ERP method tested in the present study, which can easily be adapted to such tasks. Use of real-life-like scenarios instead of artificial stimulation conditions based on a series of transiently presented images or sounds may further increase the patient compliance and collaboration in neuropsychological testing, which when associated with ERP metrics may allow to state and investigate deeper questions in cognitive and affective processes in various neuropsychiatric conditions (Sitnikova et al. 2008).

Acknowledgements The present work was supported by Scientific Research Projects Coordination Unit of Istanbul University Projects 1400-42514/2014 and 23083-58951/2015. The author EE received the DAAD stipend (57140539) during the period of this project.

Compliance with ethical standards

Conflict of interest The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Ethical approval This study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethical Committee of the Istanbul Faculty of Medicine of Istanbul University.

References

Ademoglu A, Demiralp T, Yordanova J, Kolev V, Devrim M (1998) Decomposition of event-related brain potentials into multicomponents using wavelet transform. Appl Sig Proc 5:142–151

Allison BZ, Polich J (2008) Workload assessment of computer gaming using a single-stimulus event-related potential paradigm. Biol Psychol 77(3):277–283. https://doi.org/10.1016/j.biopsycho.2007.10.014

Backus AR, Schoffelen JM, Szebényi S, Hanslmayr S, Doeller CF (2016) Hippocampal-prefrontal theta oscillations support memory integration. Curr Biol 26(4):450–457. https://doi.org/10.1016/j.cub.2015.12.048

Basar E, Bullock TH (eds) (1992) Induced rhythms in the brain. Birkhäuser, Boston

Basar E, Demiralp T, Schürmann M, Basar-Eroglu C, Ademoglu A (1999) Oscillatory brain dynamics, wavelet analysis, and cognition. Brain Lang 66(1):146–183. https://doi.org/10.1006/brln.1998.2029

Basar E, Schürmann M, Demiralp T, Basar-Eroglu C, Ademoglu A (2001) Event-related oscillations are 'real brain responses'-wavelet analysis and new strategies. Int J Psychophysiol 39(2–3):91–127. https://doi.org/10.1016/S0167-8760(00)00135-5

Basar E, Basar-Eroglu C, Güntekin B, Yener GG (2013) Brain's alpha, beta, gamma, delta, and theta oscillations in neuropsychiatric diseases: proposal for biomarker strategies. Suppl Clin Neurophysiol 62:19–54

Basar-Eroglu C, Basar E, Demiralp T, Schürmann M (1992) P300-response: possible psychophysiological correlates in delta and theta frequency channels. A review. Int J Psychophysiol 13(2):161–179. https://doi.org/10.1016/0167-8760(92)90055-G

Basar-Eroglu C, Schmiedt-Fehr C, Mathes B (2013) Auditory evoked alpha oscillations imply reduced anterior and increased posterior amplitudes in schizophrenia. Suppl Clin Neurophysiol 62:121–129

Bayram A, Bayraktaroglu Z, Karahan E, Erdogan B, Bilgic B, Ozker M, Kasikci I, Duru AD, Ademoglu A, Oztürk C, Arikan K, Tarhan N, Demiralp T (2011) Simultaneous EEG/fMRI analysis of the resonance phenomena in steady-state visual evoked responses. Clin EEG Neurosci 42(2):98–106

Bayram A, Karahan E, Bilgiç B, Ademoglu A, Demiralp T (2016) Achromatic temporal-frequency responses of human lateral geniculate nucleus and primary visual cortex. Vis Res 127:177–185

Brainard DH (1997) The psychophysics toolbox. Spat Vis 10:433–436. https://doi.org/10.1163/156856897X00357

Carvalho S, Leite J, Galdo-Álvarez S, Gonçalves ÓF (2011) Psychophysiological correlates of sexually and non-sexually motivated attention to film clips in a workload task. PLoS ONE 6(12):e29530. https://doi.org/10.1371/journal.pone.0029530

Demiralp T, Ademoglu A (2001) Decomposition of event-related brain potentials into multiple functional components using wavelet transform. Clin Electroencephalogr 32(3):122–138. https://doi.org/10.1177/155005940103200307

Demiralp T, Ademoglu A, Comerchero M, Polich J (2001) Wavelet analysis of P3a and P3b. Brain Topogr 13(4):251–267

Demiralp T, Bayraktaroglu Z, Lenz D, Junge S, Busch NA, Maess B, Ergen M, Herrmann CS (2007) Gamma amplitudes are coupled to theta phase in human EEG during visual perception. Int J Psychophysiol 64(1):24–30

Ergen M, Marbach S, Brand A, Basar-Eroglu C, Demiralp T (2008) P3 and delta band responses in visual oddball paradigm in schizophrenia. Neurosci Lett 440(3):304–308

Ergen M, Yildirim E, Uslu A, Gürvit H, Demiralp T (2012) P3 response during short-term memory retrieval revisited by a spatio-temporal analysis. Int J Psychophysiol 84(2):205–210

Ergen M, Saban S, Kirmizi-Alsan E, Uslu A, Keskin-Ergen Y, Demiralp T (2014) Time-frequency analysis of the event-related potentials associated with the Stroop test. Int J Psychophysiol 94(3):463–472. https://doi.org/10.1016/j.ijpsycho.2014.08.177

Escera C, Alho K, Schröger E, Winkler IW (2000) Involuntary attention and distractibility as evaluated with event-related brain potentials. Audiol Neurotol 5(3–4):151–166. https://doi.org/10.1159/000013877

Grossman A, Morlet J (1984) Decomposition of Hardy functions into square integrable wavelets of constant shape. SIAM J Math Anal 15:723–736

Güntekin B, Saatçi E, Yener G (2008) Decrease of evoked delta, theta and alpha coherences in Alzheimer patients during a visual oddball paradigm. Brain Res 1235:109–116

Herrmann CS, Grigutsch M, Busch NA (2005) EEG oscillations and wavelet analysis. In: Handy TC (ed) Event-related potentials: a methods handbook. MIT Press, Cambridge, pp 229–259

Kirmizi-Alsan E, Bayraktaroglu Z, Gurvit H, Keskin YH, Emre M, Demiralp T (2006) Comparative analysis of event-related potentials during Go/NoGo and CPT: decomposition of electrophysiological markers of response inhibition and sustained attention. Brain Res 1104(1):114–128

Klimesch W (1999) EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. Brain Res Brain Res Rev 29(2–3):169–195. https://doi.org/10.1016/S0165-0173(98)00056-3

Kramer AF, Trejo LJ, Humphrey D (1995) Assessment of mental workload with task-irrelevant auditory probes. Biol Psychol 40(1–2):83–100. https://doi.org/10.1016/0301-0511(95)05108-2

Lang PJ, Bradley MM, Cuthbert BN (1997) International affective picture system (IAPS): technical manual and affective ratings. NIMH Cent Study Emot Atten 1:39–58

Liu B, Wang Z, Jin Z, Song G (2010) The influence on cognitive processing from the switches of shooting angles in videos of real-world events: an ERP study. Neurosci Lett 469(3):370–374. https://doi.org/10.1016/j.neulet.2009.12.030

McArthur GM, Bishop DVM, Proudfoot M (2003) Do video sounds interfere with auditory event-related potentials? Behav Res Methods Instrum Comput 35(2):329–333. https://doi.org/10.3758/BF03202561

Mertens R, Polich J (1997) P300 from a single-stimulus paradigm: passive versus active tasks and stimulus modality. Electroencephalogr Clin Neurophysiol 104(6):488–497. https://doi.org/10.1016/S0168-5597(97)00041-5

Nessler D, Johnson R, Bersick M, Friedman D (2006) On why the elderly have normal semantic retrieval but deficient episodic encoding: a study of left inferior frontal ERP activity. Neuroimage 30(1):299–312

Polich J (2007) Updating P300: an integrative theory of P3a and P3b. Clin Neurophysiol 118(10):2128–2148. https://doi.org/10.1016/j.clinph.2007.04.019

Roy RN, Bonnet S, Charbonnier S, Campagne A (2016) Efficient workload classification based on ignored auditory probes: a proof of concept. Front Hum Neurosci 10:519. https://doi.org/10.3389/fnhum.2016.00519

Sauseng P, Klimesch W, Doppelmayr M, Hanslmayr S, Schabus M, Gruber WR (2004) Theta coupling in the human electroencephalogram during a working memory task. Neurosci Lett 354(2):123–126. https://doi.org/10.1016/j.neulet.2003.10.002

Scholz S, Schneider SL, Rose M (2017) Differential effects of ongoing EEG beta and theta power on memory formation. PLoS ONE 12(2):e0171913. https://doi.org/10.1371/journal.pone.0171913

Selimbeyoglu A, Keskin-Ergen Y, Demiralp T (2012) What if you are not sure? Electroencephalographic correlates of subjective confidence level about a decision. Clin Neurophysiol 123(6):1158–1167. https://doi.org/10.1016/j.clinph.2011.10.037

Shigemitsu Y, Nittono H (2008) Assessing interest level during movie watching with brain potentials. In: Poster session presented at the second international workshop on Kansei, Fukuoka, Japan, Proceedings, pp 39–42

Shigemitsu Y, Nittono H, Hori T (2007) Assessing the allocation of attention to audiovisual experience with the P300 elicited by vibratory probe stimuli. Jpn J Physiol Psychol Psychophysiol 25(3):277–285. https://doi.org/10.5674/jjppp1983.25.277

Sitnikova T, Kuperberg G, Holcomb PJ (2003) Semantic integration in videos of real-world events: an electrophysiological investigation. Psychophysiology 40(1):160–164. https://doi.org/10.1111/1469-8986.00016

Sitnikova T, Holcomb PJ, Kiyonaga KA, Kuperberg GR (2008) Two neurocognitive mechanisms of semantic integration during the comprehension of visual real-world events. J Cogn Neurosci 20(11):2037–2057. https://doi.org/10.1162/jocn.2008.20143

Sugimoto F, Katayama JI (2013) Somatosensory P2 reflects resource allocation in a game task: assessment with an irrelevant probe technique using electrical probe stimuli to shoulders. Int J Psychophysiol 87(2):200–204. https://doi.org/10.1016/j.ijpsycho.2013.01.007

Suzuki J, Nittono H, Hori T (2005) Level of interest in video clips modulates event-related potentials to auditory probes. Int J Psychophysiol 55(1):35–43. https://doi.org/10.1016/j.ijpsycho.2004.06.001

Takeda Y, Kimura M (2014) The auditory N1 amplitude for task-irrelevant probes reflects visual interest. Int J Psychophysiol 94(1):35–41. https://doi.org/10.1016/j.ijpsycho.2014.07.007

Tarnanas I, Tsolaki M, Nef T, Müri RM, Mosimann UP (2014) Can a novel computerized cognitive screening test provide additional information for early detection of Alzheimer's disease? Alzheimers Dement 10(6):790–798. https://doi.org/10.1016/j.jalz.2014.01.002

Tulving E, Kapur S, Craik FI, Moscovitch M, Houle S (1994) Hemispheric encoding/retrieval asymmetry in episodic memory: positron emission tomography findings. PNAS 91(6):2016–2020

Ullsperger P, Freude G, Erdmann U (2001) Auditory probe sensitivity to mental workload changes—an event-related potential study. Int J Psychophysiol 40(3):201–209. https://doi.org/10.1016/S0167-8760(00)00188-4

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.