Event Related Message Processing: Perceiving and Remembering Changes in Films with and
without Soundtrack

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Abstract

Hollywood movies provide continuous audiovisual information. Yet, information conveyed by movies address different sensory systems. For a broad variety of media applications (such as multimedia learning environments) it is important to understand the underlying cognitive principles. This project addresses the interplay of auditory and visual information during movie perception. Because auditory information is known to change basic visual processes, it is possible that movie perception and comprehension depends on stimulus modality. In this project, we report three experiments that studied how humans perceive and remember changes in visual and audiovisual movie clips. We observed basic processes of event perception (event segmentation, change detection, and memory) to be independent of stimulus modality. We thus conclude that event boundary perception is a general perceptual-cognitive mechanism and discuss these findings with respect to current cognitive psychological and media psychological theories.

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“The most exciting moment is the moment when I add the sound. . . . At this moment, I tremble.”

– Akira Kurosawa, director (as cited in Bordwell & Thompson, 1990)

Despite the fact that filmmakers are aware of the important role of sound in movies (Bordwell & Thompson, 1990), little is known about the relative contribution of visual and auditory information to film comprehension processes. Against the background that media based applications such as multimedia learning environments include filmic material for instruction and entertainment purposes it is thus important to understand the underlying cognitive processes.

In the present project, we study processes of film perception and understanding using paradigms known from event cognition research (e.g., Newton, 1973). The basic idea is that – although information in movies is continuous – humans perceive distinct events with a beginning and an end. Between two events, human observers perceive an event boundary (Newton, 1973). Event boundaries are usually determined by asking participants to segment a movie into meaningful events by pressing a button when they perceive the end of a meaningful unit and the beginning of the next meaningful unit. Event boundaries are important because the perception of such event boundaries is related to attentional costs (Huff, Papenmeier, & Zacks, 2012) and memory for situations at event boundaries is higher than memory for situations during ongoing events (Newton & Engquist, 1976). The reason for this event boundary advantage is often seen in extensive elaboration processes following event boundary perception (Zacks, Speer, Swallow, Braver, & Reynolds, 2007). Lower secondary task performance at event boundaries seems to support this approach (Huff, Papenmeier, & Zacks, 2012). Further, processes of anticipation of the future development of an action or plot are hindered at event boundaries (Zacks, Kurby,

Eisenberg, & Haroutunian, 2011). Humans represent the current activity or observation in *event models* in working memory. These can be conceived as situation models known from text comprehension literature (Zwaan & Radvansky, 1998), which describe the ongoing situation on several dimensions such as *time*, *space*, *character*, and *action* (Magliano & Zacks, 2011). Research using edited movies (with sound) instead of videos depicting naturalistic actions as stimuli showed that changes in one or more dimensions trigger the perception of an event boundary (Huff, Meitz, & Papenmeier, 2014). In the latter study, the probability to perceive an event boundary increased with increasing number of dimension changes. That is, smaller changes (e.g., if there is just a change in the number of persons present in the scene) were perceived as less interrupting as compared to larger changes (e.g., if there were changes in all four dimensions) (Huff, Meitz, & Papenmeier, 2014). In a further experiment the authors have shown that memory performance for event boundaries increased with an increasing number of dimension changes. However, because the stimulus material was audiovisual it remains an open question how sound information contributed to this effect.

The presence of auditory information might influence visual information processing in films and movies on a perceptual level (i.e. event segmentation), on the level of change detection (i.e. cut detection task), and on the memory level (i.e. long-term memory).

Among other – visual – features, sound is a central feature that cues transitions between filmic scenes and supports viewers' understanding (Hochberg & Brooks, 1996). This is not far to seek, because structural features (such as sound effects and edits) in complex auditory stimulus material (i.e. radio broadcasts, including songs and verbal messages), were shown to elicit orienting responses and are further related with higher recognition memory (Potter, Lang, & Bolls, 2008), which resembles the event boundary advantage in event cognition research

(Newtson & Engquist, 1976; see also Huff, Maurer, Brich, Pagenkopf, Wickelmaier, & Papenmeier, 2018). Empirical support for the hypothesis according to which auditory cues influence visual processing in films comes from a study that used the event segmentation task (Schwan, Hesse, & Garsoffky, 1998). The authors have shown that auditory formal filmic means such as the onset or the offset of a commentary in audiovisual educational videos trigger segmentation responses (Schwan et al., 1998). In their study, Schwan and colleagues asked participants to segment educational videos depicting actions (e.g., production processes of trousers) into meaningful events. The videos were presented in their original, audiovisual version. That is, there was no systematic variation with regard to the presentation of stimulus modalities (audiovisual vs. visual presentation.). To our knowledge, no study addressed this question in detail. In addition, it is important to note, that the auditory information of the educational videos in this study was just verbal information (i.e. there was no music).

To date, most studies that focused on memory for event boundaries have used visual dynamic scenes or silent movies (Hanson & Hirst, 1989; Newtson & Engquist, 1976). There are only a few studies that have used audiovisual stimulus material. These tested memory for event boundaries either by using video stills only, replicating the event boundary advantage (Huff, Meitz, & Papenmeier, 2014; Swallow, Zacks, & Abrams, 2009), or by using short clips from a movie, finding mixed results with regard to the event boundary advantage (Boltz, 1992). Boltz (1992) measured memory for event boundaries and non-event boundaries for the commercial movie “A Perfect Spy” (Powell & Smith, 1987; with vs. without commercial breaks), including rich auditory information. Recognition memory was measured using 3-sec clips from the movie. The author observed the event boundary advantage for recognition memory in the conditions with the commercial breaks at event boundaries. Importantly, in the condition in which the

movie was presented continuously (i.e. without commercial breaks), she did not observe the event boundary advantage for recognition memory, although memorization was significantly higher than in the condition which posited the commercial breaks at scenes that did not contain an event boundary at all. Thus, increased saliency—due to commercial breaks—increased the vividness of event boundaries finally leading to the event boundary advantage.

In summary, there is some evidence that auditory information contributes to event segmentation (Schwan et al., 1998) and basic memory processes such as the event boundary advantage for continuously presented films and movies (Boltz, 1992). However, and most important, no study has systematically studied modality influences in event perception and cognition by varying presentation modalities. This is surprising, because from research using more artificial displays, it is well known that the pure presence of auditory information alters human information processing (Meyerhoff & Suzuki, 2018). For instance, in visual search displays with all objects changing colors continuously, participants are faster to detect a target object if the sound is synchronous to the change of the target object (Van der Burg, Olivers, Bronkhorst, & Theeuwes, 2008). The authors argued that auditory and visual information is processed in an integrated way when they are presented simultaneously. Follow-up research on this “pip-and-pop” effect has shown that synchronous auditory events increased fixation duration and decreased the mean number of saccades. According to this finding, visual search benefits from freezing oculomotor-scanning of the displays (Zou, Müller, & Shi, 2012). The presence of auditory information even changes participants’ eye movements on otherwise unrelated visual stimuli. Listening to music has been shown to reduce the variability of eye movements on an otherwise unrelated photograph or movie resulting in longer fixations and fewer saccades (Schäfer & Fachner, 2014). Although these results suggest that audiovisual information is

processed differently from visual information, a direct transfer to processes of event perception is difficult.

Theories in the field of event cognition often assume that event cognition is a general perceptual-cognitive process that is independent of the modality of the stimulus material (Zacks et al., 2007). According to event segmentation theory (EST; Zacks et al., 2007), for example, the event models, which comprise information from all sensory systems, represent the currently observed action in working memory. A central component of EST is that these event models are the basis for predicting the near future (Zacks et al., 2011). Humans perceive an event boundary if these predictions and the actual state of the observed action do no longer match. In this case, the event model has to be updated. This updating process triggers elaborate processing of sensory information, thus leading to a better memory for event boundaries as compared to non-event boundaries (Newtson & Engquist, 1976). The processing of additional auditory information might reduce the available attentional resources for processing the visual information, thus reducing the saliency of the change. As a consequence, change detection performance should be lower and event boundary perception impaired. Presumably, this might attenuate the difference between event boundaries and non-event boundaries with regard to long-term memory performance.

In the present project, we aim to study event boundary perception using visual and audiovisual movie clips. From film literature, it is known that audio information is often used to “hide” large edits such as abrupt filmic cuts (Bordwell & Thompson, 1990). Indeed, continuous soundtrack and dialogues across filmic cuts create the perception of continuity although visual information is presented in a rather abrupt way (Germeys & D’Ydewalle, 2007; Magliano & Zacks, 2011; T. J. Smith, 2012). From this point of view, it is not surprising that participants

often miss large changes such as filmic cuts in (audiovisual) Hollywood movies even if they were instructed to closely pay attention to these edits. In one study on this “edit blindness effect” (T. J. Smith & Henderson, 2008), participants missed more “within scene cuts” (i.e. depicting just a change in camera position within the same filmic scene) than “between scene cuts” (i.e. depicting a change between two completely different scenes).

Experimental Overview and Hypotheses

Taken together, research on event perception and cognition consistently reports evidence for event boundary perception as a general perceptual-cognitive process. Apart from a few exceptions (e.g., Boltz, 1992) most of these studies used stimulus material that was only visual (e.g., Hanson & Hirst, 1989; Magliano & Zacks, 2011). As auditory information is well able to hide large and abrupt visual changes like filmic cuts and therefore induces the illusion of continuity (Hochberg & Brooks, 1996), the event boundary perception might depend on the saliency of the event boundary. We will report three experiments, testing basic processes that are related to event boundary perception: *event segmentation while watching movies* (Experiment 1), *change detection in movies* (Experiment 2), and *long-term memory for movies* (Experiment 3). The movie clips were presented either visually or audiovisually and depicted either an event boundary or not. The experimental series tests the following two competing hypotheses:

Hypothesis 1: Event Boundary Perception is Modality Dependent

If stimulus modality influences event boundary perception processes, *event segmentation*, *change detection*, and *memory performance* should be different for audiovisual as compared to visual dynamic scenes. More specifically, the differences between event boundaries and non-event boundaries should be less pronounced in the audiovisual condition as compared to the

visual condition. This should result in statistical interactions between event boundary and stimulus modality.

Hypothesis 1a: If auditory information contributes to event segmentation behavior (e.g., Schwan et al., 1998), we expect the difference for identified event boundaries between within- and between scene changes to be less pronounced in the audiovisual as compared to the visual presentation condition.

Hypothesis 1b: If the presence of auditory information alters basic processes of event perception (e.g., Van der Burg et al., 2008), we expect the difference for identified changes (i.e. filmic cuts) between within- and between scene changes to be less pronounced in the audiovisual as compared to the visual presentation condition.

Hypothesis 1c: If the presence of auditory information alters memory-related processes (e.g., Boltz, 1992), we expect the difference for recognition memory between within- and between scene changes to be less pronounced in the audiovisual as compared to the visual presentation condition.

Hypothesis 2: Event Boundary Perception is Modality Independent

If event boundary perception is a general perceptual-cognitive mechanism, the studied processes should be independent of stimulus modality. More specifically, we expect *no statistical interactions* between event boundary and stimulus modality. We use Bayesian repeated measures ANOVAs (JASP Team, 2018) to test the models with and without the interaction term of the factors *change* and *modality*.

Hypothesis 2a: If event boundary perception is a process that is independent of stimulus modality, we expect the difference for identified event boundaries between within- and between scene changes to be similar in the in the audiovisual and the visual presentation condition.

Hypothesis 2b: If change detection in movies is a process that is independent of stimulus modality, we expect the difference for identified changes (i.e. filmic cuts) between within- and between scene changes to be comparable in the audiovisual and the visual presentation condition.

Hypothesis 2c: If memory of movie clips is independent of stimulus modality, we expect the difference for recognition memory between within- and between scene changes to be similar in the audiovisual and the visual presentation condition.

Experiment 1: Segmentation

Although there is recent evidence that the probability of perceiving an event boundary increases with an increasing number of dimension changes (Huff, Meitz, & Papenmeier, 2014), filmic cuts are not necessarily related to event boundary perception (Schwan, Garsoffky, & Hesse, 2000). The goal of Experiment 1 was therefore to study segmentation behavior in audiovisual and visual dynamic scenes. We expect that the probability of perceiving an event boundary is higher for between scene than for within scene changes. If the presence of auditory information alters processes that are responsible for event segmentation, we expect differences between visual and audiovisual video clips. If, however, event segmentation is a general perceptual and cognitive process that is independent of the stimulus' modality, we expect event segmentation to be comparable between experimental conditions.

Methods

Participants. Twenty-six students ($M = 25.5$ years, $SD_{age} = 9.3$, 17 female and 9 male) at a German university participated in Experiment 1 for monetary compensation. All of them were native German speakers. The institutional review board of the [anonymized] approved all experiments, and all participants provided informed consent prior to testing.

Apparatus. The experiment was programmed in *PsychoPy* (Peirce, 2008). The stimuli were presented on a 23-in. LCD monitor (60 Hz, 1920 x 1080 pixels) controlled by a *MacMini* at an unrestricted viewing distance of approximately 60 cm.

Stimulus material. Stimulus material consisted of 10 clips from Hollywood motion pictures (see Appendix A). Mean shot length of a Hollywood movie (between 2.5 and 4.0 seconds; Bordwell, 2002) and mean length of event segments (between 5 and 60 seconds, depending on the nature of the stimulus material; e.g., Huff & Schwan, 2012; Zacks, Speer, & Reynolds, 2009) were used to estimate the appropriate duration of the stimulus material to get a sufficient number of event boundaries. This resulted in a duration of the clips between 5 and 6 minutes. Across all clips there were $M = 22.8$ ($SD = 9.8$) between scene changes and $M = 70.4$ ($SD = 47.4$) within scene changes.

Procedure. Participants were instructed to segment the clips into events that seemed *natural and meaningful* to them by pressing the spacebar. One half of the clips were presented with sound (audiovisual condition), the remaining half without sound (visual condition; counterbalanced across participants). The clips were presented in random order.

Results and Discussion

We analyzed the segmentation data using the *segmag package* for R (Papenmeier, 2014). First, we fitted a Gaussian distribution function around each button press of each participant. The standard deviations were adjusted to 800 ms and the offset was shifted by minus 800 ms (i.e. accounting for the fact that participants press the button after they have perceived an event boundary). The standard deviation and the offset were estimated and validated using the data from a recent experiment with animated soccer scenes (Huff, Papenmeier, & Zacks, 2012). Second, we summed up the resulting Gaussian distribution for each condition (visual,

audiovisual), resulting in two different time series for each movie clip. Third, we averaged the segmentation magnitude values across, between, and within scene changes. Note, as in most segmentation experiments, this analysis focuses on segmentation behavior by describing event boundary perception on the item level (Zacks, Kumar, Abrams, & Mehta, 2009).

We submitted the resulting values to a repeated measures ANOVA with segmentation magnitude as dependent variable and *modality* (audiovisual, visual) and *change* (between scene, within scene) as independent variables. We included the factor *movie* (10 clips from Hollywood motion pictures) as random term. As evident in Figure 1, segmentation magnitude is higher for between scene changes than for within scene changes, $F(1, 9) = 29.15, p < .001, \eta_p^2 = 0.76$. Neither the main effect of modality, $F(1, 9) = 1.31, p = .282, \eta_p^2 = 0.13$, nor the interaction of change and modality reached the level of significance, $F(1, 9) = 1.15, p = .312, \eta_p^2 = 0.11$. We thus reject Hypothesis 1a.

Figure 1

In addition, a Bayesian repeated measures ANOVA (JASP Team, 2018; Morey & Rouder, 2015; Rouder, Morey, Speckman, & Province, 2012) with default prior scales revealed that the main effect model with *Change* was preferred to the null model by a Bayes factor of 1,043,000. Further, the model with Change was preferred to the model including the interaction of Change and Modality by a Bayes factor of $1,043,000 / 272,335.501 = 3.83$ (see Supplementary material for details). Thus, the data provide moderate evidence against the hypothesis that Change and Modality interact during event segmentation. The analysis of effects confirmed that the Bayes factor for inclusion of the factor *Change* was very large ($BF_{inclusion} >$

1,000; see Table 1). This is neither the case for the inclusion of the factor *modality* nor the inclusion of the interaction of *change* and *modality* (both $BF_{\text{inclusion}} < 1$).

Table 1

As expected, between scene changes were more likely to be perceived as event boundaries than within scene changes. This replicates earlier findings according to which changes in one or more dimensions of the current event model representing the plot in working memory are perceived as a boundary between two meaningful events (Huff, Meitz, & Papenmeier, 2014; Magliano & Zacks, 2011). Importantly, this pattern of results is more likely explained by a model assuming independence of the stimulus material's modality as confirmed by a Bayesian repeated measures ANOVA, thus supporting Hypothesis 2a. The fact that segmentation behavior was not different in the audiovisual as compared to the visual presentation condition is in contrast to previous research, which has shown that auditory cues (such as the on- and offset of verbal commentaries) is related with event segmentation behavior (Schwan et al., 1998). Several differences between this study and Experiment 1 might explain the different results. First, Schwan and colleagues used educational videos depicting a single task. Thus, the visual complexity was presumably lower than those of the clips used in Experiment 1. Second, whereas there was rich auditory information in the movie clips used in Experiment, there was just a verbal commentary as sole auditory information in the Schwan et al. study.

Taken together, we conclude that event segmentation is a general perceptual-cognitive mechanism that mainly refers to *semantic processing*, addressing the detection of meaningful

object semantics which refers to Abelson's (1981) cognitive scripts as basic level categories. We take up Shapiro's, Rogers, Cordova, Turk-Browne, and Botvinick (2013) conceptualization that events resemble semantic categories as perceived objects match in event models "because they are situated near each other in an internal representational space, and they lie near to one another because they share attributes" (Shapiro, Rogers, Cordova, Turk-Browne, & Botvinick, 2013, p. 486).

Experiment 2: Change Detection

Results so far suggest that event boundary perception is a process that is based on semantic changes (i.e. changes in the present event model). During an event segmentation task, participants process semantic information in a top-down manner. However, because there is also evidence for considerable bottom-up processing during event boundary perception (e.g., Zacks, 2004), Experiment 2 was conceived to test participants' ability to detect changes in dynamic scenes on a perceptual level. Therefore, we adapted a change detection paradigm and asked participants to watch out for filmic cuts while viewing visual and audiovisual dynamic scenes depicting either within or between scene cuts (d'Ydewalle & Vanderbeeken, 1990; Schröder, 1990; T. J. Smith & Henderson, 2008; T. J. Smith & Martin-Portugues Santacreu, 2016). Whereas within scene cuts depict just a change in camera position on the scene, between scene cuts depict changes in at least one dimension of the current event model (time, space, character, and action).

If the presence of auditory information alters basic processes of event perception, we expect an interaction of event boundary and stimulus. However, if event boundary processing is a general process, we expect no interaction between *modality* and *change*.

Methods

Participants. Twenty-four new students ($M=22.8$ years, $SD_{age}=2.5$, 7 female and 17 male) at a German university participated for course credit or monetary compensation. All of them were native German speakers. Newton and Engquist (1976) reported an effect size of $\eta_p^2=0.24$ for the event boundary advantage effect in their Experiment 3 (p. 446). We aimed to achieve a statistical power of .95 for our experiments (i.e. a probability of .05 not to observe a true effect). Using an effect size of $\eta_p^2=0.20$ as an estimate for this experiment and assuming correlations of $r=.5$ between the repeated measures factors, this resulted in a sample size of 22 participants for each experiment (*G*Power*) (Faul, Erdfelder, Lang, & Buchner, 2007). Due to potential participant drop out, we tested 24 participants in each of the experiments in this study.

Apparatus. The experiment was programmed in PsychoPy (Peirce, 2008). The stimuli were presented on a 23-in. LCD monitor (60 Hz, 1920 x 1080 pixels) controlled by a MacMini at an unrestricted viewing distance of approximately 60 cm.

Stimulus material. Basis of our stimulus material were 50 Hollywood movies from 1935 to 2008 (see Appendix A). Again, we used the German dubbed versions of the movies. For the purpose of this experimental series, we extracted a basis of sixteen 5-second film clips from each movie. All of them depicted a filmic cut between the second and third second (cinemetrix database; www.cinemetrix.lv): 400 clips depicted a within scene change and 400 clips depicted a between scene change—at least one dimension of the current event model changed across the cut (see Table 2). The auditory information of 40.75% of the clips included also spoken language. In 22.50% of the clips, the sound was interrupted along with the filmic cut (such as a pause in the movie's score or an abrupt switch between the different ambient sounds, such as from road traffic to forest).

Table 2

To analyze the physical characteristics of the stimulus material, we calculated the visual activity index (*vai*) (Cutting, Brunick, & Candan, 2012; Cutting, DeLong, & Brunick, 2011). The *vai* is a means to determine luminance changes in movies and thus reflects the saliency of the stimulus material. It is calculated by subtracting from 1 the correlation of the luminance values between frames separated by another frame. High *vai* values (i.e. high luminance changes) are indicative of motion in the movie (i.e. visual change). As can be seen in Figure 2, the density distributions of the *vai* values for within and between scene change stimuli are almost identical. Importantly, visual activity did not differ across experimental conditions, $F(1, 798) = 1.83, p = .177, \eta_p^2 = .002$. Thus, any difference between between-scene and within-scene changes with regard to perceptual and memory related processes seemed not be based on differences of the physical characteristics of the stimulus material.

Figure 2

As stimuli for *Experiment 2*, we randomly selected 320 of the 800 film clips (we used the full set in Experiment 3). 160 clips depicted a within scene change and 160 clips depicted a between scene change. All clips were 5 seconds long and the filmic cut was between second 2 and 3. The mean temporal location of the cut did not differ for between and within scene changes, $M = 2.559$ seconds, $SD = 0.358$ and $M = 2.564$ seconds, $SD = 0.359$, respectively, $t < 1$. We presented one half of these clips visually (without sound) and the remaining half

audiovisually (counterbalanced across participants). In addition, we extracted 80 video clips without filmic cut as catch trials. Forty of these clips were presented visually (without sound) and 40 were presented audiovisually (counterbalanced across participants).

Finally, we checked the physical characteristics (in terms of the *vai*) of the selected video clips as before. For this analysis, we only considered the experimental clips depicting a filmic cut. We observed no significant differences between experimental conditions. Neither for the factor change, $F(1, 316) = 0.28, p = .540, \eta_p^2 = 0.001$, nor for the factor modality, $F(1, 316) = 1.46, p = .228, \eta_p^2 = 0.005$, nor for the interaction of both factors, $F(1, 316) = 1.03, p = .312, \eta_p^2 = 0.003$.

Because there are no differences between experimental conditions with regard to the physical characteristics, we conclude that any differences in the behavioral measures can be traced back to the semantic structure of the clips.

Procedure. The assignment of the stimulus modality (audiovisual vs. visual) of the video clips was counterbalanced across participants. Each participant saw a clip either in the audiovisual or visual condition. Across all participants, all clips were presented in each modality condition. For each participant, the order of the clips was chosen at random. The participants started the clips by pressing the spacebar and were instructed to press a marked key (i.e. the spacebar) whenever they perceive a filmic cut as quickly as possible without sacrificing accuracy. They were allowed to take a break between trials.

Results and Discussion

We analyzed cut detection performance in terms of the proportion of missed filmic cuts and cut detection time for successfully detected filmic cuts. We excluded the catch trials (clips without filmic cut) before the analysis.

A “miss” was defined if participants did not press the spacebar in the interval between the filmic cut and the end of the clip. We calculated a repeated measures ANOVA with change (within scene, between scenes) and modality (audiovisual, visual) as independent variables and proportion of missed filmic cuts as dependent variable. Results showed that participants missed more filmic cuts in movie clips depicting within scene changes, $F(1, 23) = 17.83, p < .001, \eta_p^2 = 0.44$, as well in audiovisual film clips, $F(1,23) = 9.33, p = .006, \eta_p^2 = 0.29$. There was no interaction of change and modality, $F < 1$.

We further studied how interruptions of the auditory information along with the filmic cut are correlated with cut detection performance. We addressed this question by calculating the correlation between the variables “soundtrack continuous” and “missed filmic cut” for the audiovisual film clips depicting between-scene changes. If discontinuous sound information helps to detect filmic cuts, we expect a negative correlation. Surprisingly, we found a null-correlation between these variables, $r < .001, p = .999$. We thus reject Hypothesis 1b and conclude that neither the availability of sound in general nor the interruption of sound information along with the film cut influences the detection of filmic cuts.

We repeated this analysis with cut detection time for successfully detected filmic cuts. In a first step, all reactions between the beginning and the filmic cut time point were coded as “invalid” and were thus excluded from the reaction time analysis (1259 of 6153 trials; 20.46%). As evident in Figure 3, there were no significant effects for sound, $F < 1$, and change, $F(1, 20) = 3.27, p = .086, \eta_p^2 = 0.14$. Again, there was no interaction of change and sound, $F < 1$.

Figure 3

As in Experiment 1, we calculated a Bayesian repeated measures ANOVA with default prior scales for the dependent variable “miss”. This analysis revealed that the main effect model with *change* was preferred to the null model by a Bayes factor of 1,857,000. Further, the model with Change was preferred to the model including the interaction of Change and Modality by a Bayes factor of $1,857,000 / 473,013.662 = 3.93$ (see Supplementary material for details). Thus, the data provide moderate evidence against the hypothesis that Change and Modality interact in change detection performance. Again, the analysis of effects also showed that the Bayes factor for inclusion of the factor *Change* was very large ($BF_{\text{inclusion}} > 1,000,000$; see Table 1). This is neither the case for the inclusion of the factor Modality nor the inclusion of the interaction of *change* and *modality* (both $BF_{\text{inclusion}} < 1$).

Most important, although the presence of auditory information impaired change detection performance (T. J. Smith & Martin-Portugues Santacreu, 2016), we did not observe an interaction of event boundary and stimulus modality, thus supporting Hypothesis 2b. Further, participants missed more filmic cuts when watching within scene change stimuli as compared to between scene changes. Thus, change detection in dynamic scenes is also sensitive to semantic changes in the plot. This replicates Smith and Henderson (2008).

As the physical properties in terms of the variability of the between and within scene stimuli are comparable, we propose that it is the semantic rather than the physical saliency of the change that alters change detection performance

Experiment 3: Memory

Experiment 3 tested if the event boundary advantage effect is present in both visual and audiovisual film clips (Newtson & Engquist, 1976). First, we expect memory for between scene

changes to be higher than memory for within scene changes. Second, if memory for dynamic filmic information depends on the event structure as revealed by the segmentation pattern in Experiment 1, we expect no difference between visual and audiovisual film clips. This would support the idea of the event boundary advantage effect as a general perceptual-cognitive process.

Methods

Participants. Twenty-four new students ($M=20.6$ years, $SD_{age}=1.7$, 22 female and 2 male) at a German university participated in Experiment 3 for course credit. All of them were native German speakers. Assuming correlations of $r = .5$ between the repeated measures factors, 22 participants are necessary to reliably (power = .99) detect effects of $\eta_p^2 = 0.15$ (Faul et al., 2007). Because our counterbalancing procedure for the within-subject factors required the number of participants to be a multiple of four we tested 24 participants.

Apparatus and stimuli. The apparatus was the same as in Experiment 2. For Experiment 3, we used the whole set of the 800 five-second clips. To eliminate any potential influences from the video clips, we counterbalanced the assignment to the modality condition (visual vs. audiovisual) and the target-distractor identity across groups of four participants. The movies were presented in their original resolution (768 x 576 pixels or 1024 x 576 pixels) in the center of the screen.

Procedure. For this experiment, we adapted the experimental procedure of studies that have tested boundary conditions of long-term memory for dynamic events such as films (e.g., Matthews, Benjamin, & Osborne, 2007; Meyerhoff & Huff, 2016). In these studies, participants were asked to identify those film clips among distractor film clips that they have seen (and encoded) the day before. The experiment was divided into two sessions. In the first session - the

learning session - participants encoded 400 film clips and in the second session - the testing session - participants were asked to identify the 400 learned film clips among 400 distractor film clips. Before the first session started, participants were told that they would need to perform a recognition test in the second session. In the first session, the participants watched their 400 target items. The clips were separated by an inter-stimulus-interval of two seconds. Following every eight clips, participants were allowed to take a break. In the second session (one day later), participants indicated for all 800 items whether or not they had been displayed in the first session. After each film clip, participants were asked to press the button “9” in case the clip was a target item and the button “1” if it was a distractor item. Both buttons were labeled accordingly. After the second session, participants received a list of the 50 movies (see Appendix A) and were asked to mark which of them they had seen within the last five years. This number varied from 1 to 30 movies. Because excluding familiar movies from the analysis did not affect the results, we will not discuss this issue further.

Results and Discussion

Memory for between scene changes was higher than memory for within scene changes. Further, memory for audiovisual dynamic scenes was superior to memory for visual dynamic scenes. These two factors did not interact (see Figure 4).

For the analysis, we calculated proportion correct with *participants* and *video clips* as random factors. Values of the F -statistic derived from by-participants ($F1$) and by-video clips ($F2$) analyses are reported separately. To control for potential influencing effects such as response bias, we also report d' as sensitivity measurement and the response criterion c as response bias (Green & Swets, 1966). We submitted all of these dependent variables to separate

repeated measures ANOVAs including change (between scene, within scene) and modality (audiovisual, visual) as independent variables.

Proportion correct. Memory performance was more accurate for between scene change stimuli than for within scene stimuli, $F(1,23) = 9.82, p = .005, \eta_p^2 = 0.30$; $F(1,399) = 6.25, p = .013, \eta_p^2 = 0.02$. Further, memory for audiovisual dynamic scenes was superior to visual dynamic scenes, $F(1,23) = 22.57, p < .001, \eta_p^2 = 0.50$; $F(1, 399) = 40.67, p < .001, \eta_p^2 = 0.09$. These two factors did not interact, $F(1,23) < 1$; $F(1, 399) < 1$.

Sensitivity. The results of the d' measure resemble the proportion correct data. Memory performance was more accurate for between scene change stimuli than for within scene stimuli, $F(1, 23) = 9.44, p = .005, \eta_p^2 = 0.29$. Further, memory for audiovisual dynamic scenes was superior to visual dynamic scenes, $F(1, 23) = 19.23, p < .001, \eta_p^2 = 0.46$. These two factors did not interact, $F(1, 23) < 1$. We thus reject Hypothesis 1c.

Response bias. Response criterion c was more conservative in the between scene change condition than in the within scene change condition, $F(1,23) = 5.64, p = .026, \eta_p^2 = 0.20$, and more conservative for visual than for audiovisual stimuli, $F(1,23) = 30.89, p < .001, \eta_p^2 = 0.57$. Again, these factors did not interact, $F(1,23) = 1.13, p = .298, \eta_p^2 = 0.05$.

Figure 4

Again, a Bayesian repeated measures ANOVA for the main dependent variable sensitivity (d') with default prior scales revealed that the main effects model with *Change* and *Modality* was preferred to the null model by a Bayes factor of 34,683.052. Further, the main effects model with *Change* and *Modality* was preferred to the model including the interaction of

Change and Modality by a Bayes factor of $34,683.052 / 9,764.327 = 3.55$. Thus, the data provide moderate evidence against the hypothesis that Change and Modality interact in recognition memory. The analysis of effects also showed that the Bayes factor for inclusion of the factors *Change* and *Modality* was moderate to large ($BF_{\text{inclusion}} > 5$; see Table 1). Again, this is not the case for the inclusion of the interaction of *Change* and *Modality* ($BF_{\text{inclusion}} < 1$).

Taken together, memory performance for dynamic scenes depicting a between scene change is superior to that for within scene changes. This finding is in line with event perception literature (Newtson & Engquist, 1976) and consistent with event segmentation theory (Zacks et al., 2007) according to which changes in the continuous stream of information trigger updating of the current event model in working memory and finally lead to the formation of a memory trace. However, the finding that this effect is independent of stimulus modality (and is also present in the audiovisual condition) is in contrast to existing literature (Boltz, 1992). Using a highly sensitive within-subjects manipulation, we were able to reveal that the event boundary advantage is a general process.

General Discussion

In three experiments, we studied how humans perceive and remember changes in dynamic scenes. Research on event perception has overwhelmingly presented evidence for a memory advantage for points in time at which important things in the plot or action change (“event boundary advantage”). However, this seems to be only true for unimodal visual stimulus material. There are only a few studies focusing on the event boundary advantage effect that have used audiovisual stimulus material in encoding and test phase. These found no event boundary advantage for recognition memory (Boltz, 1992).

We tested two competing hypotheses: If additional auditory information changes event boundary perception (presumably by reducing the available resources for change processing), we expect an interaction between event boundary and stimulus modality (Hypotheses 1a, 1b, and 1c). If, however, event boundary perception is a general perceptual and cognitive phenomenon, it should be independent of stimulus modality both for *perceptual processing* (as measured with the event segmentation, Hypothesis 2a, and the change detection task, Hypothesis 2b) and for *memory* (as measured with the recognition task, Hypothesis 2c).

Experiment 1 used audiovisual and visual clips from Hollywood movies and showed that the probability to perceive an event boundary was higher for between scene changes as compared to within scene changes. There was no difference with regard to the modality of the stimuli, thus supporting Hypothesis 2a. Experiment 2 showed that visual changes (i.e. filmic cuts in between scene stimuli) were missed more likely in the within scene change than in between-scene change condition. Again, there was no interaction with stimulus modality, thus supporting Hypothesis 2b. Considering the fact that the physical characteristics in terms of the *vai* (Cutting et al., 2012) did not differ between within and between scene changes, the results of Experiment 1 and 2 suggest that it actually is the semantic change that triggers the perception of event boundaries. In Experiment 3, we eventually could show that between scene changes were remembered at a higher level than within scene changes. Although audiovisual film clips were remembered more accurate than their visual counterparts, we did not observe an interaction of event boundary and stimulus modality, thus supporting Hypothesis 2c.

What is exactly the contribution of auditory information across the process of perceiving and remembering filmic events? First, and most important, we did not observe an interaction of stimulus modality and event structure. Thus, stimulus modality does not specifically influence

certain parts of dynamic events. Second, it is also not the case that event processing benefits from more information (in the sense of a statistical main effect) in general. This is just the case for recognition memory (Experiment 3). Here, we observed that audiovisual movie clips outperform visual movie clips (Meyerhoff & Huff, 2016). In contrast, the online-measures that are directly related to film perception (event segmentation and change detection) were independent of stimulus modality. More research is needed to specify the exact boundary conditions of the influence of auditory information on this process.

To our knowledge, this is the first study that systematically varied the modality of the stimulus material and examined the event boundary perception process as a whole (including event segmentation, cut detection, and long-term memory). The within-subjects designs that we used in the present study are more sensitive than between-subjects designs (Greenwald, 1976). In our experiments, we found no support for a statistical interaction of stimulus modality and change. One explanation for this finding is that there is a common understanding between filmmakers regarding audio editing, finally leading to a homogeneous event structure. Conversely, this does not mean that it is not possible to observe auditory influences on psychological processes. We discuss two possible strands of further research. First, it might be possible to combine video and audio information from two different movies. In this case, participants should not be able to integrate visual and auditory information, which should have profound consequences on the respective perceptual and cognitive processes. Second, further psychological variables might be more sensitive to auditory information as compared to the perceptual and cognitive measures used in this study. As an example, further research could look at the influence of sound on affective measures (e.g.; Lang, Park, Sanders-Jackson, & Wilson, 2007; Yegiyan & Lang, 2010).

Given the present results, we proceed on the assumption that the event boundary advantage effect is a general perceptual and cognitive effect that is essentially based on the processing of the semantic changes in dynamic scenes.

Theoretical Implications

The present results relate to current theories on dynamic scene perception such as the event segmentation theory (EST; Zacks et al., 2007), the attentional theory of cinematic continuity (AToCC; Smith, 2012), and the limited capacity model of motivated mediated message processing (LC4MP; Lang, 2006a; 2006b), and its predecessor, the limited capacity model of mediated message processing (LC3MP; Lang, 2000).

EST proposes that currently perceived events are represented as *event models* in working memory. These event models guide perceptions and allow observers to predict future developments of the plot or action. Whenever there is a deviation between the anticipated and the actual state of an event, observers perceive an event boundary, and consequently, the event model has to be updated (Zacks et al., 2011). This results in an elaborative processing of event boundary information, which finally leads to higher memory performance. According to event segmentation theory, *event models are multimodal*, comprising information from all sensory systems. Accordingly, event boundary perception and subordinate cognitive processes such as memory formation are independent of the modality of the stimulus material. As the physical properties in terms of the *vai* were comparable across experimental conditions and we did not observe any interaction between change and stimulus modality, we propose that it is not the perception of change on a perceptual level but rather on a semantic level that triggers event boundary perception processes.

The AToCC addresses the importance of attentional processes while watching edited movies (Smith, 2012). The author argues that the illusion of continuity when watching Hollywood movies is the result of a combination of basic effects known from *visual cognition* research and filmic editing techniques. For example, the turning head of a protagonist attracts visual attention and ultimately hiding visual disruptions (Levin & Varakin, 2004). These and further attentional cues (e.g., conversational turns, gaze shift of a protagonist) are used by the filmmakers to maintain the impression of filmic continuity. The present results support this idea, because within scene changes are less likely to be perceived as event boundaries and the cut detection rate is much lower compared to the between scene changes. Importantly, AToCC focusses on attentional and visual processing of dynamic scenes and does not explain how cognitive processing proceeds after the initial perceptual stage. As the present results show that memory for dynamic scenes benefits from successfully hiding the filmic cut, the initial perceptual processing has fundamental cognitive consequences.

In the realm of the LC3MP (Lang, 2000), relatively few studies explicitly addressed the complexity of audio information within movies and films (for a seminal review see; Lang, 1995; Lang, Potter, & Bolls, 1999). However, the LC4MP provides substantial findings in regard to the specifics of audio information. A closer investigation on attention-related auditory complexity is linked with research on audio message complexity as available processing resource (Potter, Lang, & Bolls, 2008; Lang et al., 2015; Potter, Lynch, & Kraus, 2015; Potter & Lang, 2018). Potter and Lang applied a coding scheme that allowed for a specification of auditory content changes (Acc; e.g. *novelty*), and auditory information introduced (Aii; e.g. *voice change*). The coding scheme specifies auditory information attributes in order to calculate local complexity of changes or a global index where the global Acc index provides a measure for automatically

allocated resources, and Aii provides a global index of resources required (Potter & Lang, 2018). The authors' initial study (Lang et al., 2015) showed faster response latencies for probes with high Acc. The best recognition results were achieved when Acc was high but Aii was low. A second experiment focused on voice change (VC) and voice onset (VO) to test Acc and Aii as local measures, presuming that vocal novelty results in an additional automatic resource allocation (see also Schwan et al., 1998). Although the STRTs of presented VCs and VOs compared to previously heard voices were not significantly different, the Acc for novel voices showed a significant recognition advantage. Lang et al. explained this partial effect as an indication of a steady level of available resources (no significant change in STRTs), while the novel content processing required and prompted additional resources (recognition advantage).

These findings allude to our results from Experiment 3 that showed a recognition advantage for between-scene changes, which demand a closer look on auditory novelty as an additive dimensional change at filmic cuts. The LC4MP contributions on auditory information processing render a promising path towards a rather disregarded aspect, namely, the auditory influence on event boundary perception and cognition processes in mediated messages. We therefore pursue an approach that links these findings and requirements in terms of an improved understanding of what we define as event related message processing.

What is the role of the semantic change? Are the reported effects based solely on the fact that one or more of the event model dimensions change across the filmic cut? Although our results suggest a profound influence of semantic change on visual perception and memory for dynamic scenes, there is also some evidence that physical (visuospatial) information alone influences change processing and detection (Baker & Levin, 2015). The authors built their argumentation on the 180° system of continuity editing commonly used by Hollywood cinema.

The 180° system proposes that the cameras depicting a scene should only be positioned on one side of the axis of action. A car chase, for example, should only be recorded with cameras standing on one side of the road; this preserves the direction of the cars on the screen, the direction of the cars on the screen being similar to the direction of the cars on the road. Placing the cameras on different sides of the road, changes also the directions of the cars on the screen. The impression of the chase is distorted. For visual dynamic scenes, it was shown that the mere spatial positioning of cameras influences the perception of continuity (Huff & Schwan, 2012). Baker and Levin (2015) have shown that observers' ability to detect changes across filmic cuts depended on the cameras' positions. If the positions of the cameras adhered to the 180° system of continuity editing, participants were less likely to detect changes in the depicted scene that were introduced across the filmic cut. Future research is needed to address the question of potential interactions of semantic change and visuospatial information in the perception and cognition of dynamic scenes.

Limitations

In contrast to earlier findings reported by Newton and Engquist (1976), we used film clips (extracted from Hollywood movies) with filmic cuts as stimuli rather than footage of naturalistic actions. This increased the number of potential stimuli. In our experiments, we had a basis of 800 film clips from 50 Hollywood movies (in contrast to only six film clips in the Newton and Engquist study). Hollywood movies are increasingly in the focus of cognitive research (T. J. Smith, Levin, & Cutting, 2012) as they allow for studying basic perceptual and cognitive processes. However, the use of edited Hollywood movies comes at the cost of filmic cuts. Between scene changes are always related to abrupt cuts between two shots. To avoid the

confound of using filmic cuts only in one condition, we decided to use stimuli with filmic cuts in the within and between scene change condition. Experiment 1 replicated earlier findings by showing that filmic cuts do not necessarily trigger the perception of event boundaries (Schwan et al., 2000). Instead, it was the processing of the semantic change that triggered event boundary perceptions. As the results of the reported experiments show that event boundary perception is a general perceptual (Experiment 1 and 2) and cognitive (Experiment 3) process, we believe that our results are not restricted to filmic stimuli but generalize to naturalistic stimulus material.

A further special feature of our study is that our film clips in Experiment 2 and 3 were only five seconds long. This is much shorter than those used in previous research (Boltz, 1992; Newtonson & Engquist, 1976) but allowed us to study isolated effects of semantic changes on perception and memory. It is an open empirical question of whether the reported effects of event boundary perception also apply to situations with an extended narrative context. Increasing stimulus duration is often related with an increased stimulus complexity (e.g., number of edits), which also affects recognition (Lang, Potter, & Bolls 1999).

Thus, further research that aims for the auditory content at event boundaries in regard to semantic or tonal processing would benefit from prolonged probes that allow for focusing on the auditory specifics (e.g.; spoken language, music, background noise etc.), in particular with regard to orienting responses. The advancements of the auditory message coding scheme (Lang et al.; 2015; Potter, 2018) mark an encouraging starting point in this field.

Experiment 3 tested participants' long-term memory for dynamic scenes using a visual recognition paradigm (Meyerhoff & Huff, 2016). Although recognition paradigms are widely used, it is only one of many memory measures. In event cognition research, there are also some studies that have used recall paradigms to examine event memory. For example, Boltz (1992)

tested participants' *recall* and *recognition* performance for a movie that was presented audiovisually either with or without commercial breaks at event boundaries. In her study, recall and recognition measures produced similar results; that is, boundary situations were remembered better than non-boundary situations even when recognition performance was accentuated through commercial breaks. Thus, it might be possible that recall is more sensitive to event boundary processing than recognition. This supports evidence from studies with amnesic patients, which showed that recognition and recall are tightly linked functions of declarative memory (Haist, Shimamura, & Squire, 1992). Further research is needed to clarify the role of specific memory processes in event cognition.

As stimulus material, we did not use the original English-speaking version of the movies but the German-dubbed versions. Because of its high synchronicity, dubbing almost always goes unnoticed. Given the very clear experimental findings (we did not even find an influence of interrupted sound on cut detection performance in Experiment 3), we consider it as unlikely that perfect lip-synchronicity in the stimulus might have led to different results. However, it remains an open research question how dubbing influences the studied processes.

Practical Implications

In view of new media technologies and their challenge to continuously guide recipients' attention to a narrative or course of a game the results of this experimental series have profound implications for the use of films and movies in real-world media applications (such as brand placements, the challenges of muted videos in mobile media, and multimedia learning environments). Based on the results of the present study, we conclude that it is important to consider the visual-semantic structure of the video clips. For the usage of videos in multimedia

learning environments and the proper design of test item, accordingly, it is also important to consider the event structure, because information at event boundaries is remembered better than information at non-event boundaries. Adding auditory information does not alter this effect, it just boosts memory performance in general.

Conclusion

Perceiving and remembering information in films and movies is an important human ability that requires attentional and cognitive resources. Previous research showed mixed results as to whether stimulus modality influences processes that are related to event boundary perception such as superior memory for changes than for non-changes (“event boundary advantage”). We studied the event boundary perception process using event segmentation, change detection, and a memory paradigm and manipulated stimulus modality within subjects. Our experiments have demonstrated that the event boundary perception effect is independent of the stimulus’ modality and presumably can be traced back to semantic rather than physical changes.

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Figures

Figure 1. Segmentation magnitude as a function of modality and change. Error bars represent the standard error of the mean (*SEM*).

Figure 2. Comparison of the visual activity indices (vai) of the between and within scene change stimuli used in the experiments.

Figure 3. Cut detection performance in Experiment 2. Error bars indicate within-subjects confidence intervals (Baguley, 2012).

Figure 4. Memory performance in Experiment 1. Learning and testing sessions were separated by one day. Error bars indicate within-subjects confidence intervals (Baguley, 2012).

Tables

Table 1: Analyses of effects for the Bayesian repeated-measures ANOVA testing for change and modality effects.

	Effects	P(incl)	P(incl data)	BF _{inclusion}
Experiment 1	Change	0.600	1.000	879978.605
	Modality	0.600	0.426	0.496
	Change x Modality	0.200	0.150	0.705
Experiment 2	Change	0.600	1.000	1.777×10^6
	Modality	0.600	0.533	0.760
	Change x Modality	0.200	0.119	0.540
Experiment 3	Change	0.600	0.886	5.203
	Modality	0.600	1.000	9762.153
	Change x Modality	0.200	0.195	0.967

Table 2: Detailed description of the stimuli used in the between scene change condition.

	<i>Event model dimension change</i>			
	Location	Character	Time	Action
<i>Number of clips</i>	244	376	117	280
	<i>Number of changes</i>			
	1	2	3	4
<i>Number of clips</i>	104	81	109	106

Appendix A

Movies used as basis for the stimulus material in this study.

Movie	Director	Year	Exp. I	Exp. II / III
24	Stephen Hopkins	2001		✓
300	Zack Snyder	2007	✓	✓
2001: A Space Odyssey	Stanley Kubrick	1968		✓
A Clockwork Orange	Stanley Kubrick	1971		✓
Another Woman	Woody Allen	1988		✓
Avenue Montaigne	Danièle Thompson	2006		✓
Barry Lyndon	Stanley Kubrick	1975		✓
Brokeback Mountain	Ang Lee	2005		✓
Chicago	Rob Marshall	2002		✓
Cruel Intentions	Roger Kumble	1999		✓
Dogville	Lars von Trier	2003		✓
Easy Rider	Dennis Hopper	1969	✓	✓
Eternal Sunshine of the Spotless Mind	Michel Gondry	2004		✓
Eyes wide shut	Stanley Kubrick	1999		✓
Family Plot	Alfred Hitchcock	1976		✓
Full Metal Jacket	Stanley Kubrick	1987	✓	✓
Hamlet	Franco Zeffirelli	1990		✓
Hellboy	Guillermo del Toro	2004	✓	✓
Kill Bill Vol 1.	Quentin Tarantino	2003		✓
Kitchen Stories	Bent Hamer	2003		✓
L.A. Confidential	Curtis Hanson	1997		✓

Lolita	Stanley Kubrick	1962		✓
Lost in Translation	Sofia Coppola	2003		✓
Macbeth	Orson Welles	1948		✓
Marnie	Alfred Hitchcock	1964	✓	✓
Marvin's Room	Jerry Zaks	1996		✓
Ocean's Eleven	Steven Soderbergh	2001	✓	✓
Othello	Orson Welles	1952		✓
Psycho	Alfred Hitchcock	1960		✓
Rear Window	Alfred Hitchcock	1954		✓
Romeo and Julia	Baz Luhrmann	1996	✓	✓
Romeo and Julia	Franco Zeffirelli	1968		✓
Shadow of a Doubt	Alfred Hitchcock	1943		✓
Shutter Island	Martin Scorsese	2010		✓
Sideways	Alexander Payne	2004		✓
Stage Fright	Alfred Hitchcock	1950		✓
Star Wars Episode II	George Lucas	2002		✓
Star Wars Episode IV	George Lucas	1977		✓
Star Wars Episode V	Irvin Kershner	1980		✓
Syriana	Stephen Gaghan	2005		✓
Taxi Driver	Martin Scorsese	1976	✓	✓
The 39 Steps	Alfred Hitchcock	1935		✓
The Birds	Alfred Hitchcock	1963		✓
The Leopard	Luchino Visconti	1963		✓
The Man Who Knew Too Much	Alfred Hitchcock	1956	✓	✓
The Shining	Stanley Kubrick	1980	✓	✓

The Sunshine Boys	John Erman	1996		✓
The Usual Suspects	Bryan Singer	1995		✓
Van Helsing	Stephen Sommers	2004		✓
Welcome to the Sticks	Dany Boon	2008		✓