Stereo viewing upsets cinematic continuity: Filmic cuts are more salient in 3D than in 2D movies

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Word count: 7047 words (Abstract: 199 words)

Abstract

Filmmakers have established editing rules that aim to create cinematic continuity across filmic cuts, thereby avoiding viewers' confusion despite the abrupt changes in perception. In our present project, we investigated the impact of 3D films, as opposed to 2D films, on the salience of filmic cuts. We employed a cut detection task and focused on within-scene cuts with mere changes in camera perspective. We presented short video clips to our participants and asked them to press a key whenever they noticed a filmic cut, and we measured their cut detection performance. In addition to viewing mode (2D vs. 3D presentation), we considered cross-modal auditory influences (visual vs. audiovisual presentation) on the salience of filmic cuts. Participants detected cuts more accurately and faster when the video clips were presented in 3D rather than in 2D and when the video clips were presented only visually (without soundtrack) rather than audiovisually (with soundtrack). Both factors influenced cut detection performance independently. We conclude that while the regular audiovisual presentation of films supports the filmmakers' mission to achieve cinematic continuity, filmmakers should also be aware of the additional salience of cuts that comes with 3D film presentation and consider its effects on cinematic continuity.

Keywords: cinematic continuity, filmic cuts, 3D, binocular disparity, soundtrack

The craft of filmmaking is not limited to the creation of the plot, the shots, and their editing, but includes the entire production and reception process. In addition to the question of the use of analog or digital recording formats and the presentation by means of digital or mechanical projectors tackled in recent research (Loertscher et al., 2016), we asked the question whether 3D film, as opposed to 2D film, also influences the reception process. Over the decades, filmmakers developed an understanding of human perceptual and cognitive processing resulting in the definition of editing rules designed to avoid viewers' confusion by retaining spatial continuity across cuts (Arijon, 1976; Huff & Schwan, 2012; Levin & Keliikuli, 2020). Filmic cuts regularly disrupt the visual processing by altering the viewpoint and/or information presented on the screen, but utilizing those editing rules allows filmmakers to cut movies at increasingly higher frequencies (Cutting, Brunick, et al., 2011; Cutting, DeLong, et al., 2011). In recent years, more and more three-dimensional (3D) movies were released (Mendiburu, 2009). With the 3D presentation of movies, viewers can utilize binocular disparity as an additional depth cue (Landy et al., 1995), thus resulting in a stronger perception of the depicted space within filmic scenes. As filmic cuts stitch together filmic scenes, the 3D presentation of movies might also influence cinematic continuity by changing the salience of filmic cuts, for example by introducing additional visual distortions across filmic cuts. In the present project, we studied the influence of 3D movie presentation on perceived continuity by measuring the salience of filmic cuts using a cut detection task. As accompanying auditory information (i.e. a soundtrack) impacts perceived continuity and visual attention (Meitz et al., 2020; Shimamura et al., 2015; Smith & Martin-Portugues Santacreu, 2017), we also considered cross-modal auditory influences on cinematic continuity.

In 2D movies, observers have to rely on monocular cues such as familiar size, occlusion, or depth from motion to infer depth information within the scene (Landy et al., 1995). The rise of 3D technology in movies and animations, however, introduced binocular disparity as an additional cue (created by presenting slightly different images to each eye) that viewers can use to infer depth within the filmic scene. In the following, we first review previous research that deals with the influence of a change from 2D to 3D movie

presentations on various psychological processes, such as the viewing experience, memory, or visual attention. Then, we focus on the processing of filmic cuts in movies, thereby addressing the role of cut detection as a means of studying the visual salience of filmic cuts in movie perception.

Past studies have often used subjective ratings to investigate viewers' 3D movie viewing experience, such as the feeling of presence. Presence describes the subjective feeling of "being there" in the displayed environment (Lombard & Ditton, 1997; Wirth et al., 2007). The increased perception of depth associated with 3D presentations is linked to higher feelings of presence (Baranowski et al., 2016; Ijsselstein et al., 1998). The feeling of presence is increased regardless of binocular disparity signals being "real" – recorded with two cameras – or "artificial" – recorded with one camera and converted to 3D by adding a slight offset between the images in post-production (Baranowski et al., 2016). The 3D presentation of movies also influences viewers' ratings regarding immersion. Although the term immersion is not always used consistently in the literature, we take immersion to describe the perceived technical capabilities of a system in creating a realistic and vivid environment (Gaebler et al., 2014; Sanchez-Vives & Slater, 2005; Slater & Wilbur, 1997). Viewers report stronger immersion for 3D viewing than 2D viewing (Gaebler et al., 2014) and viewers rate their experience as being perceptually more realistic and report being less distracted during 3D than 2D movie presentations (Rooney & Hennessy, 2013). However, there is also research reporting no difference in self-reported emotional arousal or satisfaction with the whole viewing experience (Rooney & Hennessy, 2013) and no effect of 2D/3D viewing mode on perceived enjoyment (Sobieraj & Krämer, 2015). There are mixed findings regarding the relation between 3D viewing and visual discomfort. Some studies reported that 3D viewing was associated with increased discomfort or even motion sickness (Baranowski et al., 2016; Keshavarz & Hecht, 2012), some results suggest no clear difference between 2D and 3D viewing on visual comfort (Pölönen et al., 2013), and another study reported that only a minority of viewers experienced discomfort through 3D viewing (Read & Bohr, 2014). Importantly, however, some effects of 3D viewing on subjective ratings can be explained by negative preconceptions regarding 3D viewing or factors associated with the 3D glasses rather than binocular

disparity itself. That is, participants watching actual 2D content through 3D glasses report more adverse effects than participants watching 2D content without glasses (Read & Bohr, 2014).

The three-dimensional presentation of movies also affects viewers' memory and visual attention. Watching a movie in 3D rather than 2D is associated with a reduced memory for product placements (both free recall and recognition) in movies (Breves & Schramm, 2019). This is particularly true for subtle product placements, such as products briefly appearing in the periphery of the screen (Terlutter et al., 2016). This reduced memory for subtle product placements is potentially caused by the guidance of viewers' visual attention to objects highlighted by binocular disparity (Yim et al., 2018). Studies investigating memory performance for objects and faces showed that binocular disparity supports the extraction of an object's depth structure into memory and thereby the generalization of memory representations across viewpoint changes (Bennett & Vuong, 2006; Burke, 2005; Burke et al., 2007). This effect is most pronounced in the absence of other depth cues such as depth from motion (Papenmeier & Schwan, 2016). In a similar manner, whereas binocular disparity can help to visually segment and encode specific images, such as forest images, into long-term memory, participants do not remember whether images of natural scenes, such as images of houses or cars, were presented with or without binocular disparity during learning (Valsecchi & Gegenfurtner, 2012). Given these constraints, binocular disparity seems to have only subtle effects on human memory of natural scenes. Regarding visual attention, however, it has been shown that adding binocular disparity to objects moving in three-dimensional space helps viewers track those objects (Viswanathan & Mingolla, 2002), thus supporting visual attention. What is still unknown, however, is whether adding binocular disparity to movies also directs viewers' attention to features filmmakers usually like to hide, such as filmic cuts.

Although each filmic cut causes abrupt changes to the information on display, the actual consequences for the processing of movies are less severe, in particular because viewers' comprehension of movies is based on sparse and stable representations of the presented narrative (Magliano & Zacks, 2011; Zacks et al., 2007, 2009). Filmmakers even developed editing rules designed to avoid viewers' confusion

by retaining spatial continuity across cuts (Arijon, 1976), thereby “hiding” filmic cuts. For instance, a temporal discontinuity, such as a gap created by dropping a few frames to the cutting floor (Hecht & Kalkofen, 2009) or a brief overlap (Shimamura et al., 2014), can improve perceived smoothness and continuity across a spatial gap. And when adhering to the respective editing rules, even severe changes across cuts, such as the replacement of objects, tend to go unnoticed by viewers (Baker & Levin, 2015; Levin & Simons, 1997; Simons, 1996). Remarkably, viewers still miss about 15 percent of the cuts even when their attention is directed toward the filmic cuts by asking viewers to press a button following each detected cut (Smith & Henderson, 2008). Filmic cuts can be divided into within-scene cuts and between-scene cuts. Within-scene cuts are filmic cuts that result from a mere change in camera perspective, thus ensuring visual continuity. Between-scene cuts are filmic cuts with changes in action, location, or characters that upset continuity. Due to the break in continuity, between-scene cuts are more salient than within-scene cuts, resulting in higher detection rates of about 90 percent for between-scene cuts compared to detection rates of about 75 percent for within-scene cuts (Meitz et al., 2020; Smith & Henderson, 2008).

Besides the type of the filmic cut, motion information (i.e. a fast moving object or a falling person) before and after the cut, as well as auditory information influence the detection of cuts (Smith & Martin-Portugues Santacreu, 2017). In their study, Smith and Martin-Portugues Santacreu (2017) studied match-action cuts and observed cut detection rates of about 86 to 93 percent. Removing motion information after but not before a filmic cut increased cut detection performance (Smith & Martin-Portugues Santacreu, 2017). Eye-movement data suggest that removing post-cut motion information resulted in increased re-orientation processes, finally leading to an increased cut detection performance (Smith & Martin-Portugues Santacreu, 2017). In addition, cuts are easier to detect when the auditory information is removed (Meitz et al., 2020; Smith & Martin-Portugues Santacreu, 2017). This finding is in line with the limited capacity model of mediated message processing (Lang, 2000). Considering the cut detection paradigm as a dual task (watching the movie and visually searching for filmic cuts), additional auditory information distracts from the search task or – positively worded – increases the viewers’ engagement in watching movies (Smith,

2012). The notion that auditory information is likely to camouflage disruptions caused by cuts is also supported by findings that auditory information is integrated into visual processing across filmic cuts, such as the auditory Kuleshov effect (Baranowski & Hecht, 2017). The auditory Kuleshov effect describes the finding that the emotional timbre of non-diegetic music influences viewers' emotional judgments of visual facial expressions.

In our present project, we focused on the influence of presenting movies in 3D rather than 2D on the salience of cuts that filmmakers usually try to hide, namely within-scene cuts across which filmmakers typically aim to maintain cinematic continuity. There are two competing hypotheses regarding the influence of 3D viewing on cut salience. On the one hand, adding binocular disparity to movies provides an additional depth cue (Landy et al., 1995) that viewers can utilize to perceive the depth structure of the filmic scenes. Because filmic cuts result in abrupt changes between filmic scenes, 3D viewing should result in stronger visual distortions across cuts, both regarding the perceived 3D structure of the scenes and the low-level disparity signals. Therefore, 3D viewing should result in an increased salience of cuts. On the other hand, previous research reported that 3D presentations could help construct richer mental representations that generalize across viewpoint changes (Bennett & Vuong, 2006; Burke, 2005; Burke et al., 2007). Because within-scene cuts cause mere changes in camera perspective, one might argue that the 3D presentation of movies helps to retain cinematic continuity across those cuts. Therefore, viewing movies in 3D should cause a reduced salience of within-scene cuts.

We studied the influence of the 3D presentation of movies on the salience of filmic cuts using the cut detection paradigm (Smith & Henderson, 2008). We instructed participants to detect filmic cuts in short video clips that were presented either in 3D or 2D and either visually or audiovisually. If the 3D viewing of movies increases the salience of filmic cuts, then cut detection performance should be higher when viewers watch video clips in 3D rather than 2D. If the 3D viewing of movies decreases the salience of filmic cuts, however, cut detection performance should be reduced. Further, we expected that cut detection performance is lower for video clips that are presented audiovisually than video clips presented only

visually (i.e. without soundtrack). This prediction would also be consistent with previous findings (Meitz et al., 2020; Smith & Martin-Portugues Santacreu, 2017). As an exploratory research question, we asked if cross-modal information (i.e. the presence or absence of the auditory soundtrack) differentially influences cut detection in 2D and 3D.

Method

Participants

Our final sample consisted of 24 students of the University of Tübingen (22 female, 19 to 36 years old, mean age 22.9 years) that participated for course credit or monetary compensation. We replaced one additional participant due to failures in complying with the task instructions. The replaced participant had hardly pressed the cut detection key (only 21 keypresses compared to the 169 to 316 keypresses of the other participants), and the few instances that it was pressed revealed a clear guessing behavior. Twenty-three participants are necessary to detect effects of $\eta_p^2 = .29$ (size of the effect of auditory information on cut detection performance reported in Meitz et al., 2020) with a power of 80% (Faul et al., 2007). To counterbalance the assignment of stimuli to conditions across participants, we required a sample size that can be divided by four and thus collected 24 participants. All but two participants (one reporting short-sightedness, one providing no details) reported normal or corrected-to-normal vision. All participants were able to utilize binocular disparity cues as indicated by the Randot SO-002 stereotest (Stereo Optical Co., Inc.) at the end of the experiment. This experiment was conducted in accordance with APA standards for ethical treatment of participants, and all participants provided written informed consent.

Apparatus and Material

Participants sat at a table and looked at a 55-inch passive polarized stereoscopic display (horizontal interleaved) located approximately 190 cm in front of them (distance between eyes and display). A keyboard was located on the table in front of them, and its spacebar was used to collect participants' responses. Keyboard responses were recorded with PsychoPy (Peirce, 2007, 2009). The display and

keyboard were connected to the same computer, so that a single machine was used both to show the movies and to record keyboard responses during the movie presentation. The participants wore circularly polarized glasses, as well as headphones. Participants wore the polarized glasses throughout the experiment to ensure that our 3D manipulation affected only the availability of binocular disparity cues but not other feature dimensions, such as brightness.

The stimulus material was selected in the following steps. First, we chose 20 movies – ranging from computer-generated animation films to live-action films – in order to study the general effect of 3D on cut salience across a wide range of films¹. Second, we identified short video clips within each film according to the following rules: (a) each clip lasted five seconds, (b) the clip contained either no filmic cut or one filmic cut, (c) the clips were spread across each film in such a way that there were no clips that occurred in direct succession in the original film. The clips that contained a filmic cut followed some additional rules: (a) each clip contained precisely one cut, (b) the cut was a “within-scene cut” (Smith & Henderson, 2008), that is only the camera perspective changed across the cut, (c) the cut should occur between 2 and 3 seconds after the start of the clip, but we tolerated deviations of up to 550 ms from this rule (actual cut onset time: range = 1.54 to 3.54 seconds, $M = 2.49$ seconds, $SD = 0.38$ seconds). Following these rules, we identified 24 clips in each movie, 16 clips with precisely one filmic cut and eight clips with no filmic cut, resulting in the selection of 480 video clips across all 20 movies. In order to achieve a broad variation in video clip content, we furthermore selected the clips so that half of the clips involved human language, whereas the remaining half involved ambient sound information (but not language cues). Because we had no hypothesis concerning the type of sound information and including it into the analysis did not change the reported results, we aggregated across sound information type in our analysis and do not discuss

¹ We used the following 20 movies, which we classified as live-action movie (L), animation movie (A), or live-action animated movie (LA) according to their use of visual effects in the scenes that we presented in the experiment: The Amazing Spider-Man (L), Asterix and Obelix: God Save Britannia (L), Avatar (A), Cats and Dogs 2 (LA), Clash of the Titans (L), Despicable Me 2 (A), Frozen (A), Gravity (LA), The Hobbit: An Unexpected Journey (L), Ice Age 4 (A), Life of Pi (L), Megamind (A), Monsters University (A), The Chronicles of Narnia: The Voyage of the Dawn Treader (LA), Rio (A), The Smurfs (LA), Spy Kids 4 (L), Transformers: Dark of the Moon (LA), Upside Down (L), World War Z (L). Further, we used Puss in Boots for the practice block.

it further. We extracted 24 further clips from an additional 3D movie according to the same procedure, to serve as practice trials. These clips were presented at the beginning of the experiment to familiarize participants with the task and did not enter the analysis.

Procedure

Each participant was tested individually in a quiet environment. After providing information on their age, gender, and sightedness, participants read the instructions and put the polarized glasses on. We instructed participants that they would see many video clips, each lasting five seconds, and that they should identify filmic cuts by pressing the spacebar as fast as possible if they saw a filmic cut. The instructions provided two examples of filmic cuts, each including screenshots of the pre-cut and post-cut scene. For each trial, we measured cut detection performance (i.e. whether participants correctly indicated the presence of a filmic cut), as well as cut detection time (i.e. the time participants required to indicate the presence of a filmic cut following its occurrence). During the practice trials, the participants received feedback on their cut detection performance following each trial. Thereafter, the participants completed the experimental trials without feedback. Each trial started with a 200 ms fixation cross followed by the video clip. Following each clip, there was a one second blank before the next trial started. Following every 80 trials, a pause screen appeared, and participants could continue the experiment by pressing a button.

Design

We conducted a two-factorial within-subjects design with the factors *viewing mode* (2D, 3D) and *modality* (visual, audiovisual). In each condition, we presented 120 video clips (80 clips with cut and 40 clips without cut), resulting in 480 trials per participant. Each participant saw each video clip only once. We counterbalanced the assignment of video clips to conditions across participants. Thus, across all participants, each video clip occurred equally often in each condition. Trials were presented in a randomized order for each participant.

Results

Data preparation

During the preparation of the data, we noticed that one video clip that was intended to contain one within-scene cut falsely contained two cuts. Therefore, we removed the data associated with this specific clip from the data prior to the analysis. All analyses are based on the trials containing a cut². Further, we removed all trials containing early responses that occurred either before the cut or less than 200 ms following the cut (46 trials; 0.60% of the data). The data and analysis script are available as open data at <https://osf.io/ph92m/>

Cut detection performance

We analyzed cut detection performance (i.e. the proportion of detected filmic cuts; see Figure 1) with a repeated measures ANOVA including the factors viewing mode (2D, 3D) and modality (visual, audiovisual). There were significant main effects for both viewing mode, $F(1, 23) = 4.50, p = .045, \eta_p^2 = .16$, and modality, $F(1, 23) = 27.21, p < .001, \eta_p^2 = .54$. The interaction of the two factors was not significant, $F(1, 23) = 0.03, p = .869, \eta_p^2 < .01$. Thus, both factors affected participants' cut detection performance independently. The participants detected the cuts more accurately when the video clips were presented in 3D rather than 2D, and when the video clips were presented visually rather than audiovisually.

² In the trials without a cut, participants falsely indicated the presence of a cut in a very low proportion of trials ($M = .01, SD = .01$).

Figure 1

Proportion of Correctly Identified Filmic Cuts as a Function of Viewing Mode and Modality

Note. Error bars indicate 95% within-subjects confidence intervals (Baguley, 2012).

Cut detection time

In the next step, we analyzed the time participants required to identify the filmic cut in all those cases where their identification was correct (see Figure 2; 89.01% of all cut trials). We conducted a repeated measures ANOVA including the factors viewing mode (2D, 3D) and modality (visual, audiovisual). The main effects of viewing mode, $F(1, 23) = 5.94, p = .023, \eta_p^2 = .21$, and modality, $F(1, 23) = 9.21, p = .006, \eta_p^2 = .29$, were both significant, the interaction was not, $F(1, 23) = 0.46, p = .506, \eta_p^2 = .02$. The results of this analysis matched with the results of the cut detection performance analysis. That is, participants detected the filmic cuts faster when the video clips were presented in 3D rather than 2D, as well as when the video clips were presented visually rather than audiovisually.

Figure 2*Cut Detection Time as a Function of Viewing Mode and Modality*

Note. Error bars indicate 95% within-subjects confidence intervals (Baguley, 2012).

Exploratory analyses: Stability of viewing mode effect

With our experiment, we showed for the first time that participants detected cuts more accurately and faster when video clips were presented in 3D rather than in 2D. To further investigate this significant influence of viewing mode on both cut detection performance and cut detection time, we analyzed the stability of this effect across multiple potential influence factors, namely cut onset time, time within the experiment, movie type, and camera shot scale. Please note that in contrast to our primary analyses that balanced video content across experimental conditions, this is no longer the case in the following. We applied the Greenhouse-Geisser correction for all ANOVA effects that violated the sphericity assumption as indicated by a significant Mauchly's test.

Our first exploratory analysis investigated the influence of cut onset time within a video clip on cut detection performance and time. One could argue that the eyes need some time to adapt to the disparity in the clips and that our short clips might thus penalize 3D continuity. If this had been the case, the effect of

viewing mode on cut detection should have been stronger for cuts that occurred early after the onset of the video clip than for cuts that occurred later. Therefore, we performed a median split on cut onset time ($Mdn = 2.5$ s) and conducted two repeated measures ANOVAs including the factors viewing mode (2D, 3D) and cut onset time (early, late), once with cut detection performance and once with cut detection time of correct responses as the dependent variable (see Table 1). There was a significant influence of viewing mode on cut detection performance, $F(1, 23) = 4.65, p = .042, \eta_p^2 = .17$, and cut detection time, $F(1, 23) = 6.52, p = .018, \eta_p^2 = .22$. While the main effect of cut onset time was not significant for cut detection performance, $F(1, 23) = 0.05, p = .823, \eta_p^2 < .01$, there was a significant main effect of cut onset time on cut detection time, $F(1, 23) = 28.30, p < .001, \eta_p^2 = .55$. Participants took longer to identify cuts occurring early within a video clip than cuts occurring late within a video clip. This could be explained by the increasing expectation to detect a cut as time progresses within a given video clip. Importantly, however, the interaction of viewing mode and cut onset time was not significant for both cut detection performance, $F(1, 23) = 2.65, p = .117, \eta_p^2 = .10$, and cut detection time, $F(1, 23) = 0.53, p = .475, \eta_p^2 = .02$, indicating that cut onset time did not systematically influence the effect of viewing mode. The descriptive data also support the conclusion that our short clips did not systematically penalize 3D continuity (see Table 1). That is, if anything, the influence of viewing mode on cut detection performance was smaller (rather than larger) for cuts that occurred early after the onset of the video clip.

Our second exploratory analysis investigated the effect of habituation. Although we performed 24 practice trials to ensure that participants familiarized themselves with the experimental setup before formal testing, one might argue that viewers habituate to 3D after more extended periods of watching, with the effect of viewing mode vanishing over time. Therefore, we conducted two repeated measures ANOVAs including the factors viewing mode (2D, 3D) and time within the experiment (first third, second third, last third), once with cut detection performance and once with cut detection time of correct responses as the dependent variable. For cut detection performance and cut detection time respectively, we observed a significant main effect of viewing mode, $F(1, 23) = 4.43, p = .046, \eta_p^2 = .16$, and, $F(1, 23) = 7.43, p = .012$,

$\eta_p^2 = .24$, but neither a main effect of time within the experiment, $F(2, 46) = 0.65, p = .524, \eta_p^2 = .03$, and, $F(1.57, 36.05) = 0.30, p = .690, \eta_p^2 = .01$, nor an interaction of time within the experiment and viewing mode, $F(2, 46) = 0.48, p = .621, \eta_p^2 = .02$, and, $F(1.35, 31.16) = 0.66, p = .467, \eta_p^2 = .03$, were significant. Although the descriptive data (see Table 1) indicated that the influence of viewing mode might have been strongest in the middle of the experiment and weakest toward the end of the experiment, the interaction was not significant. Thus, it is unlikely that the cut detection advantage of 3D-viewing will disappear with further habituation.

With our third exploratory analysis, we investigated the viewing mode effect across different movie types. We thus classified our 20 movies according to their use of visual effects as: animation movie ($n = 7$), live-action animated movie ($n = 5$), and live-action movie ($n = 8$). We then conducted two repeated measures ANOVAs including the factors viewing mode (2D, 3D) and movie type (animation movie, live-action animated movie, live-action movie), once with cut detection performance and once with cut detection time of correct responses as the dependent variable. For cut detection performance, there was as marginally significant main effect of viewing mode, $F(1, 23) = 3.23, p = .086, \eta_p^2 = .12$, a non-significant main effect of movie type, $F(1.53, 35.22) = 2.17, p = .139, \eta_p^2 = .09$, and a non-significant interaction of viewing mode and movie type, $F(2, 46) = 1.41, p = .254, \eta_p^2 = .06$. For cut detection time, there was as significant main effect of viewing mode, $F(1, 23) = 6.57, p = .017, \eta_p^2 = .22$, a significant main effect of movie type, $F(2, 46) = 8.21, p = .001, \eta_p^2 = .26$, and a non-significant interaction of viewing mode and movie type, $F(2, 46) = 1.76, p = .184, \eta_p^2 = .07$. Post-hoc paired t -Tests showed faster cut detection times for animation movies than live-action animated movies, $t(23) = -3.04, p = .006, d_z = -0.62$, and live-action movies, $t(23) = -3.87, p = .001, d_z = -0.79$, with no significant difference in cut detection times between live-action animated movies and live-action movies, $t(23) = -0.90, p = .376, d_z = -0.18$. Thus, while movie type did not modulate the effect of viewing mode on cut detection, cuts were detected faster for animation movies than for movies containing live-action. Further, the descriptive data (see Table 1) suggest that it might be valuable to further explore in future research whether movies including animation might be more sensitive to viewing mode

effects on cut detection time, whereas live-action movies might be more sensitive to viewing mode effects on cut detection performance. Based on the non-significant interaction of viewing mode and movie type in our present data, however, we conclude that movie type did not influence the effect of viewing mode on cut detection in our experiment.

Our fourth and final exploratory analysis investigated whether the viewing mode effect varied with camera shot scale. We classified the camera shot scale for all our video clips before the filmic cut and after the filmic cut as close-up, medium, or long. After that, we determined whether camera shot scale decreased across the filmic cut (*closer*; $n = 86$), increased across the filmic cut (*longer*; $n = 74$), or remained unchanged ($n = 159$; 46 x close-up, 81 x medium, 32 x long). In a first step, we analyzed whether a change in shot scale across the cut influenced the viewing mode effect with two repeated measures ANOVAs including the factors viewing mode (2D, 3D) and change in camera shot scale (changed across cut, unchanged across cut), once with cut detection performance and once with cut detection time of correct responses as the dependent variable. For cut detection performance and cut detection time respectively, we observed a significant main effect of viewing mode, $F(1, 23) = 4.59, p = .043, \eta_p^2 = .17$, and, $F(1, 23) = 5.68, p = .026, \eta_p^2 = .20$, but neither a main effect of change in camera shot scale, $F(1, 23) = 0.99, p = .331, \eta_p^2 = .04$, and, $F(1, 23) = 0.33, p = .574, \eta_p^2 = .01$, nor an interaction of change in camera shot scale and viewing mode, $F(1, 23) = 0.85, p = .366, \eta_p^2 = .04$, and, $F(1, 23) = 0.12, p = .730, \eta_p^2 = .01$, were significant. Thus, we did not observe any significant influence of the change in camera shot scale across the cut on cut detection in general, and no significant interaction of change in camera shot scale and viewing mode in our data. In a next step, to further investigate potential influences of camera shot scale, we analyzed the trials with changed and unchanged camera shot scale separately, again once with cut detection performance and once with cut detection time of correct responses as the dependent variable. For the trials with changed camera shot scale, we ran two repeated measures ANOVAs including the factors viewing mode (2D, 3D) and type of scale change (closer, longer). For trials with unchanged camera shot scale, we ran two repeated measures ANOVAs including the factors viewing mode (2D, 3D) and camera shot scale (close-up, medium, long).

The only significant effect for those analyses was a significant main effect of the type of scale change on cut detection time, $F(1, 23) = 6.05$, $p = .022$, $\eta_p^2 = .21$. Cut detection was faster if the camera shot scale increased across the filmic cut than if it decreased across the filmic cut. All other main effects and interactions were not significant, all $F_s \leq 3.92$, $p_s \geq .060$, $\eta_p^2_s \leq .15$. However, it is important to note that based on the descriptive data (see Table 1), it seems valuable to investigate further the interaction between camera shot scale and viewing mode in future experiments. The effect of viewing mode might only apply to close-ups and medium shots, but not long shots.

Table 1

Exploratory analyses investigating the stability of the viewing mode effect

	Cut Detection Performance (in %)				Cut Detection Time (in ms)			
	Viewing Mode				Viewing Mode			
	3D		2D		3D		2D	
	<i>M</i>	95% CI	<i>M</i>	95% CI	<i>M</i>	95% CI	<i>M</i>	95% CI
Cut Onset Time								
Early	89.15	[88.34, 89.96]	88.96	[88.10, 89.82]	870	[862, 879]	893	[880, 906]
Late	89.98	[89.22, 90.74]	87.85	[86.88, 88.82]	835	[825, 844]	845	[833, 857]
Time Within The Experiment								
First Third	89.88	[88.25, 91.52]	89.20	[87.90, 90.51]	851	[835, 866]	871	[856, 886]
Second Third	89.08	[87.98, 90.18]	87.15	[85.63, 88.68]	852	[841, 863]	884	[863, 905]
Last Third	89.57	[88.00, 91.14]	89.00	[87.36, 90.65]	857	[843, 872]	862	[842, 882]
Movie Type								
Animation Movie	90.11	[88.43, 91.79]	88.69	[87.35, 90.03]	827	[813, 841]	857	[845, 870]
Live-Action Animated Movie	89.76	[88.66, 90.85]	90.23	[88.96, 91.50]	852	[838, 866]	881	[864, 898]
Live-Action Movie	88.96	[88.17, 89.76]	87.02	[86.02, 88.01]	876	[865, 888]	872	[861, 883]
Camera Shot Scale								
Changed Across Cut	88.96	[87.89, 90.03]	88.29	[87.48, 89.10]	857	[841, 872]	869	[858, 879]
Unchanged Across Cut	90.18	[89.30, 91.06]	88.54	[87.76, 89.32]	849	[838, 861]	869	[859, 880]
<i>Changed Across Cut</i>								
Closer	87.55	[86.04, 89.06]	88.23	[86.56, 89.90]	868	[851, 884]	897	[877, 917]
Longer	90.43	[88.99, 91.88]	88.52	[86.92, 90.12]	844	[822, 865]	846	[825, 867]
<i>Unchanged Across Cut</i>								
Close-Up	91.15	[90.23, 92.06]	90.25	[89.01, 91.49]	839	[821, 858]	869	[847, 891]

Medium	90.26	[88.88, 91.63]	87.34	[85.99, 88.69]	848	[834, 862]	878	[850, 906]
Long	88.72	[86.99, 90.46]	88.94	[87.16, 90.72]	879	[846, 912]	861	[834, 887]

Note. The table depicts 95% within-subjects confidence intervals (Baguley, 2012).

Discussion

We investigated the influence of the mode of movie presentation on cinematic continuity by studying the effects of viewing mode (2D, 3D) and modality (audiovisual, visual) on cut detection performance. Cuts were detected faster and more accurately when the video clips were presented in 3D rather than 2D and when the video clips were presented visually rather than audiovisually. Both manipulations affected cut detection performance independently. Our results on the influence of the 3D presentations of movies on the detection of filmic cuts provide new insights into the influence of 3D movie presentations going beyond previous research studying subjective ratings of viewing experience (e.g., Baranowski et al., 2016; Rooney & Hennessy, 2013). Further, our results on the influence of audio on the detection of visual filmic cuts show that the soundtrack reduces the salience of the cut, which provides a replication of previous research (Meitz et al., 2020; Smith & Martin-Portugues Santacreu, 2017).

Regarding the influence of 3D movie presentations on cut detection performance, there were two competing hypotheses. On the one hand, 3D viewing of movies could result in higher cut detection performance due to stronger visual distortions across cuts caused by the abrupt change in the perceived 3D structure of the scenes and abrupt changes in the low-level disparity signals across cuts. On the other hand, 3D viewing could help viewers generalize across viewpoint changes (Bennett & Vuong, 2006; Burke, 2005; Burke et al., 2007), thus increasing cinematic continuity and reducing cut detection performance. Our results support the former hypothesis, namely the easier detection of filmic cuts in 3D movies. Whether this increased cut detection performance is caused by abrupt low-level changes in binocular disparity or rather by higher-order processes that signal a stronger conflict between the pre-cut and post-cut scene regarding the perceived depth structure, based on binocular disparity, cannot be resolved with our present experiment.

What our experiment does show is that adding 3D to movies requires filmmakers to consider its influence on cinematic continuity, therefore potentially requiring adapted editing rules (Mendiburu, 2009).

We investigated the salience of cuts by means of cut detection performance. In order to achieve a robust measure of cut detection performance, we presented short video clips with many repetitions of the cut detection task within each participant. Further, we studied the salience of cuts that filmmakers usually try to hide, namely within-scene cuts, such as changes in camera perspective, across which filmmakers typically aim to maintain cinematic continuity. Other than being within-scene cuts, we did not apply further criteria for selecting the filmic cuts. Given that previous research has shown that cut detection performance varies across different cut types, such as within-scene cuts and between-scene cuts (Meitz et al., 2020; Smith & Henderson, 2008), it would be interesting to conduct future research investigating the influence of 3D movie presentations on cinematic continuity with more specific types of filmic cuts. Further, whereas our exploratory analysis provided no significant evidence for the habituation to 3D across time, our descriptive data suggest that the effect of 3D might have been weaker toward the end of our experiment. As most previous research reporting 3D effects also used rather short video clips (e.g., Baranowski et al., 2016; Gaebler et al., 2014; Ijsselstein et al., 1998; Keshavarz & Hecht, 2012; but see Rooney & Hennessy, 2013), it seems valuable for future research to further investigate the idea of the habituation to 3D effects with longer movies. If our findings generalize to longer movies and different cut types, then we are likely dealing with a two-fold effect of 3D. First, the well-established effect that 3D increases presence and immersion (Baranowski et al., 2016; Gaebler et al., 2014), and second the effect that it increases the salience of cuts. Filmmakers should then take this into account and better tone down the spatiotemporal magnitude of the cuts they use.

In our experiments, we measured the salience of filmic cuts by directly asking viewers to detect these cuts. Thus, we directed the viewers' attention toward these cuts. Nevertheless, the viewers still missed about 10 percent of the filmic cuts despite their full attention being directed toward them, similar to previous research that employed a similar cut detection task (Meitz et al., 2020; Smith & Henderson, 2008; Smith &

Martin-Portugues Santacreu, 2017). Furthermore, similar to previous research showing that cut detection is sensitive to manipulations in the type of filmic cuts (Smith & Henderson, 2008), post-cut motion (Smith & Martin-Portugues Santacreu, 2017), and the removal of auditory information (Meitz et al., 2020; Smith & Martin-Portugues Santacreu, 2017), we found that cut detection performance was influenced by manipulations of the auditory information and the 2D/3D presentation of movies. Given the intentional nature of the cut detection task, the question remains to what extent these results can be generalized to film reception when viewers do not focus on the cuts.

On the one hand, the influence of 3D on cut salience during normal film viewing might be stronger than observed in our cut detection experiment. Focusing on cuts resulted in near ceiling cut detection performance, leaving hardly any room for the salience effect. On the other hand, the increased salience of cuts caused by 3D presentations might only be relevant when viewers are looking for cuts and might go unnoticed when viewers focus on the narrative rather than the cut structure of the film. Therefore, future research should investigate the increased salience of filmic cuts with 3D presentations also during normal film perception by focusing on more indirect measures of cut salience, such as the strength of the orienting response following filmic cuts (Lang et al., 2000), the detection of cross-cut continuity errors, such as changes in protagonists' clothing (Baker & Levin, 2015), or the increase in saccade frequencies that indicates attentional reorienting following filmic cuts (Smith & Henderson, 2008; Smith & Martin-Portugues Santacreu, 2017). That is, 3D movie presentations might cause larger orienting responses, higher continuity error detection rates, or higher saccade frequencies following cuts than 2D movie presentations.

Our finding that stereo viewing upsets continuity seems surprising when considering the Attentional Theory of Cinematic Continuity (AToCC; Smith, 2012). According to AToCC, viewers' perception of continuity depends on their expectations and the guidance of their visual attention. The presentation of attentional cues before the filmic cut, such as pointing gestures or off-screen sounds, triggers attentional shifts. Filmic cuts that coincide with such attentional shifts maintain continuity and cause these cuts to go unnoticed. Whether one watches a film in 3D or 2D does not alter the visual content of the

depicted scene. Therefore, at first glance, the reduced cinematic continuity that comes with 3D contradicts AToCC; especially if one assumes that it is the low-level disparity signal that affects continuity, similar to other low-level visual image properties (Valuch et al., 2017). However, it is also possible that it is not the disparity signal per se but the percept of 3D space that triggers cut detection. Some attentional cues designed to direct the viewers' attention on the 2D screen might work differently in 3D film, thus impairing cinematic continuity just as predicted by AToCC. Therefore, 3D films might require special editing techniques, such as blending disparity across cuts to facilitate 3D point-of-attention jumps from shot to shot (Block & McNally, 2013). By investigating which 3D editing techniques are particularly successful in creating the impression of cinematic continuity, future research could help to understand better which features of 3D films can disrupt cinematic continuity in the first place.

To further investigate the role of the low-level disparity signal on cinematic continuity, future research should try to quantify the amount of disparity present in the filmic scenes. Such quantification could be done, for example, by running image comparison functions on the individual frames of the video clips. If one uses video clips that vary in the amount of disparity present before and after the cut, and the disparity sometimes changes across the cut, one could investigate whether there is a linear association between the (change of) low-level disparity signal and cut detection. However, such a study should also include further measures, such as measures of narrative engagement. A respective analysis would then allow one to quantify and tease apart the role of the low-level disparity signal and other higher-level influence factors on perceived cinematic continuity.

By combining the cut detection task that we used in the present experiment with measures of immersion, future research could further disentangle the relation between 3D viewing and cinematic continuity. One could speculate, for example, that the influence of 3D viewing on cut salience is mediated by immersion. More specifically, whereas 3D viewing causes an overall increase in immersion (Gaebler et al., 2014), 3D cuts might also upset immersion to a stronger degree than 2D cuts, thus resulting in increased cut detection.

Our exploratory analysis also revealed an overall effect of movie type on cut detection. Cuts in animated films were quicker to detect than cuts in films containing live-action. We can only speculate about the reasons for this finding. On the one hand, this could be caused by rather global features that might differ between animation and live-action, such as the use of color and contrast, or the spatial layout of objects within the scene. On the other hand, viewers may process animated films and live-action films differently. From research on pictures, for example, we know that pictures containing a photographed face are more robust against slant than pictures containing the drawing of a face (Hecht et al., 2014). Thus, the processing of film containing live-action might also be more robust against cuts, resulting in slower cut detection. Future research should shed further light on the potential differences involved during the processing of filmic cuts and cinematic continuity in animated and live-action films. In our view, the current emergence of more and more live-action adaptations of animated films, such as *Dumbo* or *Beauty and the Beast*, may provide a promising terrain for such research.

Conclusions

Hollywood movies consist of a sequence of single shots concatenated by filmic cuts. Over the last centuries, mean shot duration has constantly decreased, with newer Hollywood movies being cut with a shot duration below 4 seconds (Cutting, Brunick, et al., 2011). Given this high frequency of filmic cuts, it is fascinating that viewers usually have the impression of cinematic continuity. This applies all the more when considering that abrupt viewpoint changes cause severe challenges to the maintenance of visual attention (e.g., Huff et al., 2009, 2010; Meyerhoff et al., 2017), as well as the memory for objects and scenes (e.g., Bülthoff & Edelman, 1992; Garsoffky et al., 2007; Meyerhoff et al., 2021; Papenmeier & Huff, 2014). Filmmakers also seem to be aware of such effects and, as a consequence, try to “hide” filmic cuts to avoid viewers’ confusion (Arijon, 1976). However, one should not forget that the processing of movies is also driven by the narrative plot (Germeys & D’Ydewalle, 2007; Magliano & Zacks, 2011; Schwan & Ildirar, 2010), potentially rendering the perceptual influences across filmic cuts less important. For example, if there is a causal match across cuts, viewers will automatically fill in perceptual information that was missing

across the cut (Brockhoff et al., 2016; Papenmeier et al., 2019; Strickland & Keil, 2011). Therefore, our new finding that the 3D presentation of movies increases the saliency of filmic cuts does not necessarily imply that this increased saliency disrupts viewers' understanding of the movie. Notwithstanding the need for further investigation, our results show that filmmakers should be aware of the increased saliency of cuts in 3D film compared to the traditional 2D film. This saliency has to be toned down if it is merely an unwanted side-effect, or it can be exploited for dramatic effect.

Data availability statement

Data and analyses scripts (for the statistical programming language R) have been made publicly available via the Open Science Framework and can be accessed at <https://osf.io/ph92m/>

Disclosure statement

The authors declare that they have no conflict of interest.

Author Contributions

FP, HH, and MH developed the study concept and the study design. FP programmed the experiment. Data collection was performed by a student assistant under the supervision of FP. Data analysis was performed by FP and MH. FP and MH drafted the manuscript, and all authors provided critical revisions. All authors approved the final version of the manuscript for submission.

Acknowledgements

We thank Eleni Sianni for her help during data collection. HH acknowledges the support of the Wissenschaftskolleg zu Berlin.

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