The Editing Density of Moving Images Influences Viewers' Time Perception: The Mediating Role of Eye Movements

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Abstract

The present study examined whether cinematographic editing density affects viewers' perception of time. As a second aim, based on embodied models that conceive time perception as strictly connected to the movement, we tested the hypothesis that the editing density of moving images also affects viewers' eye movements and that these latter mediate the effect of editing density on viewers' temporal judgments. Seventy participants watched nine video-clips edited by manipulating the number of cuts (slow- and fast-paced editing against a master-shot, unedited condition). For each editing density, multiple video-clips were created, representing three different kinds of routine actions. The participants' eye movements were recorded while watching the video, and the participants were asked to report duration judgments and subjective passage of time judgments after watching each clip. The results showed that participants subjectively perceived that time flew more while watching fast-paced edited videos than slow-paced or unedited videos; by contrast, concerning duration judgments, participants overestimated the duration of fast-paced videos compared to the master-shot videos. Both the slow- and the fast-paced editing generated shorter fixations than the master-shot, and the fast-paced editing led to shorter fixations than the slow-paced editing. Finally, compared to the unedited condition, editing led to an overestimation of durations through increased eye mobility. These findings suggest that the editing density of moving images by increasing the number of cuts effectively altered viewers' experience of time and add further evidence to prior research showing that performed eye movement is associated with temporal judgments.
Keywords: Time Perception, Eye Movements, Moving Images, Editing

1. Introduction

Over the last twenty years, there has been a growing interdisciplinary dialogue between cognitive neurosciences and audiovisual studies in the attempt to enhance our understanding of the audiovisual (e.g., film) viewing experience (D'Aloia and Eugeni, 2014; Smith et al., 2012; Tan, 2018). This dialogue has given rise to interdisciplinary research fields crossing film theory and experimental sciences such as "psychocinematics" (Shimamura, 2013), "neurocinematics" (D'Aloia and Eugeni, 2014; Hasson et al., 2008), or "film neuroaesthetics" (Grodal and Kramer, 2014; Smith, 2017). Researchers have examined the cognitive processes involved in viewing moving images, trying to understand how the filmmaker techniques influence these processes (Shimamura, 2013; Smith, 2013; Smith et al., 2012). Also, drawing from embodied theories of cognition (e.g., Barsalou, 1999; Gallese, 2005; Varela et al., 1991), research has focused on the neural correlates of film experience (Gallese and Guerra, 2012, 2014, 2020; Hasson et al., 2008), trying to understand the impact of different film styles on the spectator's brain activity (Heimann et al., 2017; Trifonova, 2014) and the role of bodily engagement in aesthetic experience (Gallese and Guerra, 2012, 2020; Heimann et al., 2019).

To provide evidence about how viewers cognitively, behaviorally, or neurologically respond to moving images, researchers have applied the methods of cognitive science, empirical psychology, and cognitive neuroscience (e.g., eye-tracking, memory or reaction time tests, electrophysiology, functional magnetic resonance) to the study of the film viewing experience. For instance, using eye-tracking techniques to measure viewers' gaze, several studies have examined how spectators' visual attentional processes are influenced by cuts (i.e., discontinuities from one camera shot to the next; Cutting, 2005) or by techniques of editing together distinct camera shots such as 'continuity editing'[1] (e.g., Hirose et al., 2010; Loschky et al., 2015; Schwan and Ildirar, 2010; Smith, 2012; Smith and Henderson, 2008). Other studies have used functional magnetic resonance (fMRI) to investigate event segmentation and film comprehension (Magliano and Zacks, 2011), examining brain responses to the cues given by continuity editing as well as viewers' subjective perception of continuity/discontinuity across different types of cuts. In a behavioral and high-density EEG experiment, Heimann et al. (2014) have examined how camera movements (i.e., Steadicam, dolly, zoom) influenced the activation of viewers' motor cortex (more specifically, the mirror system). Camera movements were used to simulate an observer's movement towards an observed actor performing goal-related actions (e.g., grasping): Steadicam was found to activate the strongest brain response, as this technique was most able to simulate human approaching.

It is worth observing that, contrary to the studies that considered movies just a more "naturalistic" surrogate of experimental stimuli such as static images or words (e.g., Sonkusare et al., 2019; Vanderwal, Eilbott, & Castellanos, 2019), this trend of studies specifically focused on semiotic, stylistic, and technical features of audiovisual texts – such as editing and camera movements – to provide empirical evidence on specific viewers' cognitive processing in watching moving images and living the film viewing experience.

Among the various cognitive processes underlying film experience, less attention has been given to time perception and to the study of how cinematographic language may affect spectators' experience of time (Cohen et al., 2017; de Wied et al., 1992; Manoudi, 2015). Nonetheless, starting from Deleuze's (1986, 1989) work, time has been considered as a fundamental trait of the cinematic images (Carruthers, 2016; Currie, 1995; Doane, 2002; Girgus, 2018; Mulvey, 2006; Stewart, 2007; Terrone, 2017). The temporal unfolding of actions represented in a film can be handled through editing (Bordwell & Thompson, 1993): With proper use of editing, filmmakers can manipulate diegetic time (i.e., duration of an action as represented in the film) as opposed to real time. In other terms, using various editing techniques, viewers' perception of the duration of represented actions can be altered (i.e., expanded or shortened) compared to their real duration.

Thus far, most studies have focused on viewers' perception of temporal continuity (Smith, 2004, 2006; Smith et al., 2012), while little research has examined how viewers' perception of time varies depending on the editing density of moving images. For instance, in an experimental study examining viewers' duration experience under conditions of suspense (de Wied, 1991), two editing techniques (i.e., ellipsis and compression) were used to manipulate the screen duration of events and test the effect of variations in the pace of temporal succession of breakpoints (i.e., the beginnings or endings of events) on viewers' duration experience in a following suspense scene. Specifically, the breakpoints followed each other at a faster pace in the condensed condition than in the ellided one. The results showed that viewers perceived that the suspense scene lasted longer when preceded by condensed rather than ellided scenes, possibly because viewers tended to tune themselves to the condensed discourse's faster pace. Likewise, another study (de Wied et al., 1992) examined viewers' duration experience in suspense scenes preceded by introductory scenes manipulated using three different degrees of compression. The results showed that the suspense scene was perceived to last longer when the introductory scenes were more condensed. In a more recent study, Manoudi (2015) tested the impact of three different editing styles on perceived duration. Five scenes (e.g., a man smoking a cigarette, a woman preparing and drinking some tea) were edited to produce three distinct time manipulations: real-time, compressed-time, expanded-time. Portions of an action were left out in the compressed-time editing; By contrast, portions of the action were added using multiple shots in the expanded-time editing (since the editing resulted in different durations across the three versions of each scene, static frames were added at the beginning and the end of each video clip). The results showed that participants overestimated the duration of expanded-time scenes (in which an action lasted longer than it does in the real world) compared to that of compressed-time (in which an action lasted less than it does in the real world) and real-time scenes.

Within psychological literature on time perception, it is well-known that individuals' explicit temporal judgments often do not match the physical, temporal length of dynamic events, even though the underlying mechanisms are not yet fully understood (for reviews see Eagleman, 2008; Lacquaniti et al., 2014; Matthews and Meck, 2016). For instance, biases in duration judgments of visual stimuli have been observed during saccadic movements (Binda et al., 2009; Morrone et al., 2005). Also, supra-modal effects have been observed (i.e., the estimated duration of visual stimuli is affected by a motor effector that is not directly related to vision): It has been found that performing (e.g., Merchant and Yarrow, 2016; Yokosaka et al., 2015) as well as preparing and programming hand movements (Hagura et al., 2012; Tomassini and Morrone, 2016; Yabe and Goodale, 2015) during a (visual) timing task leads to distortions in duration judgments, including both compression and dilation of time. A possible explanation offered to account for these action-related temporal distortions is the idea that movement actively structures time perception, even when the timing task does not explicitly require it. Latest theories and research have argued that the human ability to estimate time durations is embedded in the motor system, whose functions – such as planning, executing, and monitoring of movements and actions − are highly reliant on implicit timing (Fernandes and Garcia-Marques, 2019; Gallagher, 2011, 2016; Gavazzi et al., 2013; Merchant and Yarrow, 2016; Wittman, 2009, 2014). In support of this claim, the activation of brain areas that are strongly implied in motor functions has been consistently observed during time estimation tasks (Coull et al., 2016; for a metanalysis see Wiener et al., 2010).

Along this line of reasoning, some theorists have recently proposed an embodied account of time perception (Droit-Volet et al., 2013, 2020; Wittmann, 2014), which differs from other existing models (e.g., Gibbon et al., 1984; Treisman et al., 1990; Zakay and Block, 1997) as it claims that motor simulations and bodily states play a critical role in time judgments. In more detail, it has been argued that the conscious representation of time descends from a temporal integration of bodily feelings over time (e.g., Craig, 2009; Wackermann et al., 2014; Wittmann, 2013, 2014), including those associated with self-generated movements (Fernandes and Garcia-Marques, 2019). This representation could be generated in the insula cortex – a primary receptive area for afferent signals from the body (Craig, 2009) − as some research has found an accumulating pattern of neural activity in this brain structure during timing tasks, resembling a cumulative temporal process (Wittman et al., 2010).

Although still debated, the theory of embodied time has received some empirical support. For instance, Meissner and Wittmann (2011) have found progressive increases in cardiac periods (indexing physiological activity) during the encoding of temporal intervals, and as an association between this increase and the duration estimations' accuracy. Moreover, accuracy was associated with higher interoceptive awareness (i.e., the ability to detect bodily changes). In a recent study, Fernandes and Garcia-Marques (2019) have shown that dynamic facial muscle activity (measured using electromyography) is related to the subjects' representation of time (i.e., the duration estimation of a visual stimulus): Higher muscle deactivation latency and lower activation amplitude of the corrugator-supercilii predicted estimates of longer duration. On a related note, previous research has highlighted the role of sensory-motor experience in the duration judgment of emotional facial expressions: It has been shown that the inhibition of spontaneous facial mimicry cancels out the overestimation of duration of emotional compared to neutral faces (Effron et al., 2006). These findings suggest that time perception could be an embodied process based in motor information and somatic (proprioceptive-kinesthetic) feelings related to movement.

Further evidence comes from research showing that motion-related properties of visual stimuli can induce distortions in temporal judgments. For instance, individuals tend to perceive the duration of moving stimuli as longer than that of stationary stimuli even if their physical duration is the same; also, speed and temporal frequency have been shown to dilate our perception of time (Eagleman, 2008; Kanai et al., 2006; Lacquaniti et al., 2014). Recent studies have found that the accuracy of temporal judgments depends on the correspondence between the stimulus's kinematic profile the and the observer's motor repertoire, suggesting that perceived duration could rely on internal models of action (Gavazzi et al., 2013). In an experimental study where participants were shown pictures of a ballerina performing various ballet steps (Nather et al., 2011), participants judged the duration to be longer when the ballerina performed a ballet step rather than when she was in a rest position, even if the images were displayed for the same length of time. This distortion has been interpreted as due to the reactivation in memory (or motor simulation) of the movements associated with the body postures represented in the picture: In this view, judgments of the duration of observed actions would be based on the reactivation or re-enactment of sensory-motor states (Droit-Volet and Gil, 2009; Droit-Volet, 2014; Droit-Volet et al., 2013). The authors have further interpreted the results suggesting that the internal simulation of the body posture requiring more movement would have produced an acceleration of the internal clock through the mediation of heightened arousal levels generated by the perception of this posture. According to internal clock models (Gibbon et al., 1984; for a discussion see Allan, 1992), when the internal clock runs faster, more time units (pulses, oscillations) are accumulated, and time is judged longer.

As noted by Sobchack (1982, 2016), moving images comprise different types of movement: first, the movements of objects and/or actors as represented in the film (diegetic movement); second, the movement between the images/frames (the editing); third, the camera movements and, fourth, the optical movements of the camera lens (the zoom). The fifth type of movement concerns the spectator: their eye movements while watching the film. So far, most research on audiovisual experience has used eye movements (i.e., saccades and fixations) as a real-time measure of viewers' attentional and cognitive processing of films (e.g., Loschky et al., 2013; Smith et al., 2012; Smith, 2013). By contrast, based on previous research showing a relationship between the individual's own performed movement and duration judgments (e.g., Fernandes and Garcia-Marques, 2019), in this study, we measured eye movements as a marker of oculomotor activity to examine the effects of editing density on viewers' time perception.

1.2 The Present Study

The present study aimed at contributing to the understanding of audiovisual experience in two ways. First, we examined whether the cinematographic editing density affects viewers' perception of time. In more detail, we manipulated the number of cuts (i.e., the density of editing) by comparing a slow- and fast-paced editing against an unedited condition (master-shot). Both slow- and fast-paced editing used an increased number of cuts compared to the unedited condition, and − for each editing density − three video-clips were created representing different kinds of routine actions (e.g., to drink water). Notably, while previous studies examining the effects of editing on viewers' time perception have used editing techniques that alter screen duration compared to the actual duration of an action or event (Manoudi, 2015; de Wied, 1991), in this study editing did not affect screen duration of the represented actions. Second, based on embodied models that conceive time perception as strictly connected to the movement (both performed and observed), we tested the hypothesis that editing density affects the spectators' eye movements and that these latter mediate the effect of editing on viewers' temporal judgments.

To our knowledge, this is the first study considering the role of both viewers' performed movement (i.e., gaze) and observed movement (i.e., the actor performing the routine actions on the screen and the editing of these actions) for time perception in moving images: Within research on audiovisual experience, there is scant evidence examining the influence of editing on viewers' experience of time and eye movements have been generally used as an index of viewers' attentional and cognitive processing of films (e.g., Loschky et al., 2013; Smith et al., 2012). By contrast, within psychological research on time perception, most studies have used experimental stimuli presented for very short time intervals (≤ 1 second), so that it is not clear yet whether the results may extend to duration judgments of longer dynamic stimuli such as moving images (Eagleman, 2008; Lewis and Miall, 2003).

Concerning time perception, two measures were used (Droit-Volet and Wearden, 2016): Duration judgments (DJs), which were assessed using retrospective verbal estimation (Grondin, 2010; Mioni et al., 2014) and subjective passage of time judgments (PoTJs). DJs correspond to the ability to estimate the temporal length of a given stimulus, while PoTJs refer to the subjective impression of how fast or slow time seems to pass (e.g., "time flew", "time dragged"). Notably, prior research (Wearden, 2005; Wearden and Droit-Volet, 2016) has shown no significant relationship between these two forms of temporal judgment, so that individuals may report that time flew while watching an action movie compared to a relaxation movie but retrospectively judge that the duration of the action movie was longer (Wearden, 2005).

Two standard oculomotor measures were employed concerning eye movements: fixation durations (FDs) and saccade amplitudes (Smith & Mital, 2013). Fixation durations provide information about whether gaze is stationary (i.e., few, long fixations) or shifts (i.e., the more the eyes move, the shorter fixation durations). Saccade amplitudes reflect the extent of distance traveled by the eye during the movement.

The hypotheses of the study were as follows:

H1) We expected that participants would report that time passed faster while watching slow- and fast-paced editing videos compared to unedited, control videos.

H2) Because velocity and temporal frequency have been found to dilate perceived duration (Kanai et al., 2006), we expected that durations of slow- and fast-paced editing videos would be overestimated compared to unedited, control videos.

H3) We expected participants to exhibit shorter fixation durations (i.e., more frequent eye movements) while watching slow- and fast-paced editing videos compared to unedited, control videos. We also predicted that edit density would selectively affect fixation durations, but not saccade amplitudes: Variations in this parameter generally depend on how objects are distributed within the visual array (Smith & Mital, 2013) and a constrained composition of the shots characterized the videos used in this study.

H4) Additionally, we hypothesized that eye movements would mediate the effect of editing density on DJs. In other terms, based on previous research showing a relationship between the temporal dynamics of performed movement and duration judgments (Fernandes and Garcia-Marques, 2019), we expected that slow- and fast-paced editing would lead to overestimation of durations through faster ocular activity (indexed by shorter fixation durations). Finally, we also examined the association between saccadic amplitude and time perception with to observe whether DJs would be related to both oculomotor activity parameters. However, in the absence of prior research, we offer no formal hypothesis for this relationship and included this analysis as an exploratory aspect of our research.

2. Method

2.1 Sample

The sample consisted of 70 undergraduate students (mean age = 20.72, SD = 3.26; 82% female). 30% of the sample were first-year Psychology students, while the remaining participants were recruited from the Faculty of Liberal Arts and Philosophy. All participants were identified as Caucasian.

The study was conducted in accordance with the ethical standards of the Declaration of Helsinki and participants were free to withdraw from the study at any time. They provided written informed consent by signing a printed consent form. The participants were volunteers and received no compensation for their participation in the study.

2.2 Stimuli

Ten video-clips were created and used as experimental stimuli. A professional film crew shot the videos in a professional studio with two sets of seven cameras and nine different shot sizes and angles[2].

The videos were edited in order to obtain three conditions corresponding to as many degrees of editing density: (A) master shot (no editing); (B) slow-paced editing; (C) fast-paced editing. In the master shot version (A), an unedited condition, the entire action was shown from a frontal perspective, medium shot, without cuts. Slow-paced videos (B) were edited using 'match-on-action' cuts (i.e., the editor cuts from one shot to another view that matches the first shot's action). The videos consisted of five shots from different angles and distances, including an establishing shot (i.e., the first shot of a new scene designed to show where the action is taking place). They were edited according to the rules of continuity editing. Finally, fast-paced videos (C) presented a higher number of cuts (10-12) and more angle/distance changes (7) than slow-paced videos, including point-of-view shots (i.e., angles that shows what the actor is looking at in the first person), plongées (i.e., high-angle shots where the camera looks down on the actor), close-ups, and cut-in shots (i.e., showing some part of the scene in detail). Editing C was intended to imitate the so-called 'intensified continuity editing' (Bordwell, 2006; see also Cutting and Candan, 2015) by increasing the number of shots and changing the angle without violations of continuity rules. An example of the degrees of editing density is shown in Fig. 1.

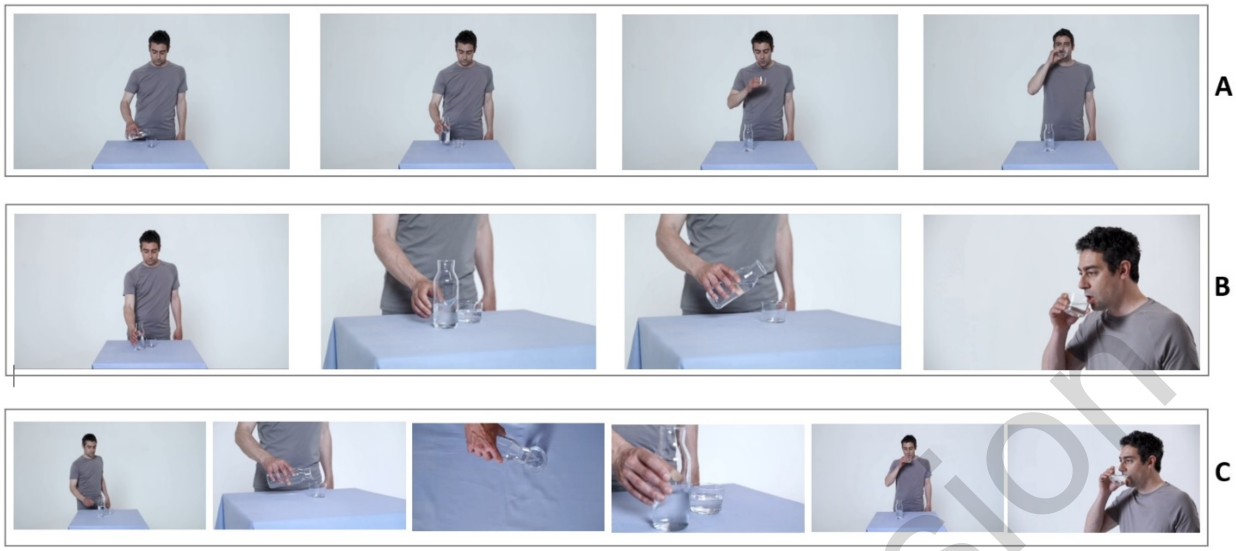


Fig. 1. An example ("drinking water") of how video clips were edited: A) Master-shot; B) Slow-paced editing; C) Fast-paced editing.

For each degree of editing density, three clips were created representing different types of goal-directed routine actions (Heichmann et al., 2014). An actor was instructed to perform the following actions: (1) to pour some water into a glass and drink it ("drinking water"); (2) to cut a half-loaf of bread into two parts with a knife ("cutting bread"); (3) to move a glass and a loaf of bread on a table ("moving objects"). Notably, differently from Manoudi (2015), duration was maintained constant across the different action types (i.e., although differently edited, the three videos of the same action had the same duration). Overall, the clips had similar durations: 13.5s for "drinking water", 11s for "cutting bread" and 11s for "moving objects".

Finally, a tenth video was created to control for a possible novelty effect. In this video-clip, the actor gently moved his hands upwards on the table in a circular motion. This control video was edited in the master shot (unedited) version only, lasted 12s, and was presented at the beginning of each session as the first stimulus.

2.3 Procedure

Participants were tested individually in a quiet and comfortably lit room. Upon arrival, they read and signed a printed consent form. Then, they were asked to sit in front of a 19-inch computer screen. Each participant watched all video clips (within-subject design) while their eye-movements were recorded. The video-clips (1280 x 1024 pixels, Audio-Video Interleaved format) were administered in a randomized order by the Tobii Studio Software 3.4.8 except for the control video clip, which was always presented at the beginning of the experimental session to control for a potential novelty effect (data about the control video were not analyzed).

After watching each video, participants were asked to answer a set of questions concerning time perception. Moreover, to prevent the participants from adopting a counting strategy (Rattat and Droit-Volet, 2012), we used a distracting question (i.e., meant to focus the participant's attention on the video-clip in general, rather than on the processing of time) inviting them to provide a short oral description of the content of the video immediately after watching each clip ("*Now please tell me all you can remember about what happened in this video clip*").

Finally, participants were debriefed and thanked for their participation in the study.

2.4 Measures

Eye movements. A Tobii X-120 eye-tracker (drift: < 0.3°, accuracy: 0.5°, 120 Hz) was used. Gaze data were collected and analyzed using the Tobii Studio 3.4.8 software. Among the parsing algorithms implemented in the Tobii Studio, we employed the Tobii I-VT fixation filter, based on the velocity of the eye's directional shifts (velocity threshold 30°/s, minimum fixation duration 60 ms). Participants first calibrated to the eye tracker using a 9-point calibration procedure. Wearing glasses or contact lenses did not diminish the accuracy of either the calibration or of the recording. However, due to technical problems, four participants' data were lost.

Since the stimuli employed in this research consisted of video-clips (i.e., dynamic images), gaze data were preprocessed to deal with smooth pursuits (SP), a type of eye movement (distinct from saccades) that allows the eyes to closely follow slow-moving objects by keeping their image near the fovea. Parsing algorithms implemented in most commercial eye-tracking systems do not identify SP, which are instead misclassified as a sequence of "phantom" fixations and saccades (Mital et al., 2011). SP were thus filtered out using dynamic Areas Of Interest (AOIs) drawn around moving objects: The fixations identified in these areas until the object stopped moving were interpreted as SP. Fixations were also manually doubled checked using raw X/Y coordinates. The preprocessing excluded 10.5% of fixations for the master-shot, 6.3% for the slow-paced edited, and 3.7% for the fast-paced edited videos. A total of 16,864 fixations remained for analysis.

Two standard oculomotor measures were considered: fixation durations (FDs) and saccade amplitudes (i.e., the distance in visual degrees between the previous fixation location and the current fixation location). Both measures were extracted from the raw data and the mean was calculated for each video-clip.

Time perception. Following prior literature (Droit-Volet and Wearden, 2016; Sucala et al., 2010; Wearden, 2015), we decided to maintain subjective passage of time judgments (PoTJs) and duration judgments (DJs) as separate variables, both in data collection and analysis. PoTJs were measured using two items: Participants were asked to express a time passage judgment on a 9-point Likert scale (from 1 = "*time dragged*" to 9 = "*time flew*"; Wearden, 2005; Sucala et al., 2010) and an action speed judgment (from 1 = "*very slow*" to 9 = "*very fast*"; Droit-Volet and Wearden, 2016). Bivariate correlation was $r = .72$. A composite mean score was computed.

DJs were measured using a retrospective (i.e., participants were not informed in advance that they would be asked to perform a temporal task) verbal estimation task (Mioni et al., 2014) requiring participants to provide an estimate of the duration of each clip in seconds by indicating a numerical value between 1 and 30 seconds. However, the experiment employed a within-subject design and the temporal task was administered after each video (i.e., ten times). Block et al. (2018) noted that after completing a single trial, participants become aware of the importance of the temporal aspect (as in prospective paradigms). Thus, it is likely that participants got used to the procedure expecting questions about time perception.

Following standard practice (Sucala et al., 2010), accuracy scores were then computed as the ratio between the participant's estimate and the actual video duration. Scores greater than 1 indicate temporal overestimation, while scores lower than 1 represent temporal underestimation.

2.5 Analytic Strategy

Data were analyzed by using Linear Mixed Models (LMM; Hoffman & Rovine, 2007), nesting the nine video-clips (Level 1, repeated) within Subject (Level 2). Editing Density was entered as a fixed factor, while Subject and Type of Action were entered as random effects. In this way, we could test the effect of the Editing Density on each dependent variable controlling for individual differences among participants as well as differences among the three types of actions.

For each variable, an empty model was run first, including random differences among videos only. Type III tests and parameter estimates were used to determine the effect of editing density. Bonferroni adjusted pairwise comparisons were used to analyze significant mean differences (SPSS EMMEANS COMPARE command).

The mediation effect of editing through eye movements on time perception was tested using the macro MLmed for SPSS (for details, see Rockwood, 2017; Hayes & Rockwood, 2020). Slow- and fast-paced editing were compared to the master-shot using a binary predictor variable (0 =

unedited, 1 = edited). Since all participants watched all the videos, the between-level effect of the predictor was not included in the model. Thus, the paths from editing density to the mediators (path *a*) and editing density to time perception (path *c'*) were estimated at the within-subject level only. The nine videos were nested within-subject (Level 2 cluster variable). Mean fixation durations (in milliseconds) and saccade amplitudes were included as Level 1 mediators. Two analyses were run, one for each dependent variable separately (DJs and PoTJs).

Finally, a time-course analysis was performed comparing mean fixation durations across 500 ms time bins locked to each cut onset, as previous studies have revealed an increase in fixation durations from early to later phases during the exploration of visual scenes (e.g., Pannasch et al., 2008; Smith & Mital, 2013; Unema et al., 2005). This additional analysis is reported in the Supplementary Materials.

3. Results

Descriptive statistics are displayed in Table 1.

Table 1. *Means and Standard Deviations of the Study Variables*

	Master-shot	Slow-paced	Fast-paced
Eye-movements			
Fixation Mean Duration (FD, ms)	428.53 (206.84)	356.09 (138.95)	322.60 (109.38)
Saccade amplitude	5.07 (1.91)	4.91 (1.63)	4.96 (1.36)
Temporal Judgments			
Passage of time judgments (PoTJs)	5.25 (1.65)	5.40 (1.55)	5.81 (1.56)
Duration judgments (DJs)	1.08 (.40)	1.15 (.49)	1.18 (.50)

3.1 The Effect of Editing Density on Eye Movements

The analysis yielded a significant effect of Editing Density on FDs, $F(2,227.83) = 39.67$, $p = .000$. Pairwise comparisons showed that both slow-paced (mean difference = 65.82, SE = 11.48, $p = .000$, 95% CI: 38.09, 93.55) and fast-paced editing (mean difference = 100.61, SE = 11.48, $p = .000$, 95% CI: 72.96, 128.26) led to shorter fixations than the master-shot video clip. Also, fast-paced editing led to shorter fixations than slow-paced editing (mean difference = 34.79, SE = 7.86, $p = .000$, 95% CI: 15.88, 53.71). The parameter estimates and variance components for the empty and tested models are reported in the Appendix (Table 1).

The results also showed no significant effect of Editing Density on saccade amplitudes, $F(2,237.37) = 2.06$, $p = .130$. The parameter estimates and variance components for both the empty and tested models are reported in the Appendix (Table 1).

Overall, slow- and fast-paced editing triggered a higher number of fixations but shorter in duration than the master-shot[3], thus indicating higher gaze mobility. By contrast, editing density did not influence saccade amplitudes.

3.2 The Effect of Editing Density on PoTJs

The analysis yielded a significant effect of Editing Density on PoTJs, $F(2,311.58) = 9.70$, $p = .000$. Parameter estimates are shown in Table 2. Pairwise comparisons showed that fast-paced (mean difference = .55, SE = .13, $p = .000$, 95% CI: .24, .86) but not slow-paced editing (mean difference = .15, SE = .12, $p = .604$, 95% CI: -.13, .43) led to judge that time passed faster than the master-shot video clips. Likewise, fast-paced editing led to perceive time as passing faster than slow-paced editing (mean difference = .40, SE = .13, $p = .005$, 95% CI: .10, .71).

The parameter estimates and variance components for both the empty and tested models are reported in the Appendix (Table 2).

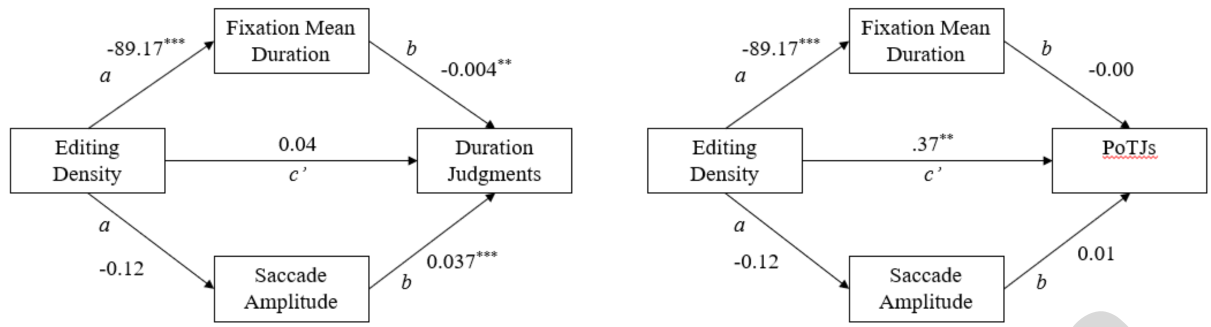
3.3 The Effect of Editing Density on DJs

The analysis yielded a significant effect of Editing Density on DJs, $F(2,308.35) = 4.81$, $p = .009$. Parameter estimates are shown in Table 2. Pairwise comparisons showed that fast-paced (mean difference = .08, SE = .03, $p = .017$, 95% CI: .01, .14) but not slow-paced editing (mean difference = .06, SE = .03, $p = .056$, 95% CI: -.00, .12) led to overestimate duration compared to the master-shot video clips. No difference emerged between fast-paced and slow-paced editing (mean difference = .02, SE = .03, $p = 1.000$, 95% CI: -.04, .08).

The parameter estimates and variance components for both the empty and tested models are reported in the Appendix (Table 2).

3.4 The Mediating Role of Eye Movements

The results of mediation analyses are shown in Fig. 2. Consistent with the hypothesis, FDs mediated the effect of editing density on the accuracy of DJs, but not the effect on PoTJs. Saccade amplitude was not a significant mediator.



Indirect Effects:

FMD: Estimate = .03, SE = .02, p = .003, CI = [.01, .06]

Saccade amplitude: Estimate = -.00, SE = .01, p = .352, CI = [-.01, .00]

Indirect Effects:

FMD: Estimate = .02, SE = .05, p = .742, CI = [-.08, .11]

Saccade amplitude: Estimate = -.00, SE = .01, p = .904, CI = [-.02, .01]

$^{*} p < .05$, $^{**} p < .01$, $^{***} p < .001$.

Fig. 2. Within-person level direct and indirect effects of Editing Density on DJs and PoTJs through mean fixation duration. For path *b* coefficients, those on top are from the within-subject model (Level 1) and those on the bottom in parentheses are from the between-person (Level 2) model. All path coefficients and indirect effect estimates are unstandardized. CI = 95% confidence interval.

4. Discussion

The present study focused on viewers' time perception while watching moving images. Drawing from both audiovisual studies on viewers' time experience and experimental research on time perception, we tested whether the way in which moving images are edited (i.e., the frequency of cuts, or editing density) affects the viewer's time perception – specifically, two forms of temporal judgment: duration and subjective passage of time judgments. Second, we tested whether the viewer's eye movements mediated this effect.

The results were overall consistent with the hypotheses. First, editing density affected both types of temporal judgments. Concerning PoTJs, the participants perceived that time flew more while watching fast-paced edited videos than slow-paced or unedited videos; by contrast, concerning DJs, the participants overestimated the duration of fast-paced videos to the master-shot videos, with slow-paced ones falling in between. Thus, these results suggest that the editing of moving images – by increasing the number of cuts – was effective at altering viewers' experience of time: A more frequent editing of images representing the same action (drinking water, cutting bread, moving objects on a table) influenced both the accuracy of DJs (in the direction of overestimation) and the subjective perception of time passage (in the direction of a speeding up of the flow of time). Although these results may appear contradictory, they are consistent with prior research showing that DJs and PoTJs are two distinct and independent forms of temporal judgment (Wearden, 2005; Wearden and Droit-Volet, 2016; Cavaletti and Heimann, 2019). While the mechanisms and neurophysiological bases of DJs have been largely studied and debated (e.g., Wittmann, 2009, 2013), the mechanisms underlying PoTjs are not yet well understood (Droit Volet and Wearden, 2016; Jones, 2019). Our findings are consistent with experimental research showing that moving (vs. stationary) stimuli, higher speed, and higher temporal frequency expand our duration estimations (e.g., Eagleman, 2008; Kanai et al., 2006; Lacquaniti et al., 2014). Notably, while this research has employed visual stimuli (e.g., flickering) presented for very brief time intervals (< 1 sec), our results showed that a higher frequency of cuts leads to an overestimation of the duration of longer-lasting stimuli (although still in the range of seconds). Different hypotheses have been advanced to explain the influence of temporal frequency and speed on DJs (Cai and Eagleman, 2015). For instance, change-based models of time perception have proposed that the brain may use the number of changes occurring in a stimulus as an information source to estimate the passage of time (Gibson, 1975; Poynter, 1989): the higher the number of changes, the longer the duration of the stimulus. Thus, the temporal frequency could thus serve as a cue of the rapidity of change (Kanai et al., 2006). A second hypothesis refers to a transient increase in the tick rate of the internal clock governing time perception (Kanai et al., 2006).

Overall, however, significant effects were limited to fast-paced editing, while slow-paced editing failed to produce the expected modifications of DJs and PoTJs. This may indicate that manipulating a small number of cuts is not sufficient to influence viewers' experience of time.

The present study's original contribution is that − based on embodied models that conceive time perception as strictly connected to movement − we also measured viewers' eye movements. First, we found that editing density affected participants' eye movements: Both the slow- and the fast-paced editing generated shorter fixations than the master-shot, and the fast-paced editing also led to shorter fixations than the slow-paced editing. Thus, the higher the number of cuts, the shorter the participants' fixations (i.e., the more the participants moved their eyes on the screen). In other words, an accelerated sequence of shots triggered faster oculomotor activity – the viewers' gaze adapted to the more rapid sequence of visual information. As expected, edit density had no significant effect on saccade amplitude, that is, on the average distance between fixations. This result may be mostly due to the fact that the videos displayed few elements (an actor, some objects, a blank background) that were generally positioned in the central portion of the scene.

Second, we found that fixation durations were related to DJs, but not to PoTJs and mediated the effect of editing density on DJs. In other words, compared to the master-shot (unedited condition), editing density led participants to overestimate the temporal durations of the video-clips and this effect was explained by increased eye mobility. This result is consistent with prior research concerning action-related temporal distortions and can be interpreted as providing further evidence for a motor component in duration judgment. Our results also seem compatible with previous research showing that dynamic facial muscle activity is associated with duration judgments (Fernandes and Garcia-Marques, 2019) and suggesting an embodied view of time perception, according to which proprioceptive-kinesthetic feelings generated from muscle activation can serve as information to estimate duration (Craig, 2009; Wittmann, 2014). There is evidence that extraocular muscle afferent signals are involved in oculomotor control and attention deployment (Balslev et al., 2012; Weir et al., 2000). and ocular-proprioception may play a role in guiding hand movement (Wilmut et al., 2006). Also, it has been shown that we have direct (though limited) awareness of our eye movements (Mahon et al., 2018). Thus, a speculative hypothesis is that ocular-proprioceptive signals could be part of the bodily states that function as an internal reference for time estimation according to the embodied model. Under this hypothesis, fast-paced videos would have determined a temporary increase of interoceptive inputs (i.e., increased rate of gaze shifts) leading to longer judged durations (Craig, 2009).

Alternatively, one could also argue that manipulating cinematographic language in our study led to dilated time estimates by influencing attention. Thus, perhaps, editing density led to increased frequency of attention shifts (as indexed by FDs), which determined an overestimation of subjective duration. This temporal distortion would be accounted for by attentional models of prospective timing (Thomas and Weaver, 1975; Zakay and Block, 1997; Zakay, 1989). In general, attentional models predict that time estimation will vary depending on the amount of information-processing activity (Boltz, 1991; Tse et al., 2004). When the individual's sole task is to judge duration (i.e., there is no distracting secondary task), estimated duration lengthens as a function of the amount of information in the judged interval (Fraisse, 1963; Thomas and Brown, 1984) or of its complexity (Thomas and Weaver, 1975). By contrast, when the individual's attention is diverted to nontemporal aspects of the stimuli or a concurrent task, estimated duration decreases as a function of the amount of information being processed (Block et al., 2010). The underlying idea is that the less attention is allocated to the passage of time, the fewer the internal clock's pulses being accumulated (Block et al., 2018).

Our results are consistent with attentional models' predictions if one considers the experiment design as a single-task paradigm. However, even though the study did not employ a dual-task paradigm, the participants were asked to describe each video's content to divert their attention from the temporal aspect. Thus, editing density should have led to compressed DJs, under the hypothesis that slow- and fast-paced editing required more attentional processing to the viewer than the master-shot. Even so, one could argue that the question we used to divert attention was ineffective (e.g., the content of the video-clips consisted of simple routine actions), and viewers were able to attend duration. Therefore, although we interpret our results as compatible with embodied models, we cannot exclude alternative explanations.

Notably, within the theoretical framework of attentional models, oculomotor activity is conceived as an indirect measure of attention deployment (and thus of cognitive load). Although the relationship between eye movements and movements of attention is still controversial (Smith and Schenk, 2012), it is generally agreed that the eyes and attention tend to shift together (Mahon et al., 2018) and that the oculomotor and the attentional systems are tightly integrated into the brain (Corbetta et al., 1998; de Haan et al., 2008). Moreover, it is well-known that attention can modulate time perception, and, for this reason, it has been argued that distinguishing an actual mechanism underlying subjective duration from additionally involved cognitive processes represents a methodological challenge (Wittmann, 2013).

Finally, in this study, we explored the relationship between time perception and saccade amplitude. Although editing density did not affect saccade amplitudes (and consequently there was no mediation effect), these latter were nonetheless positively associated with DJs, but not with PoTJs. In other terms, longer amplitudes led to overestimate duration (independent from editing cuts). Although the result of this exploratory analysis might indicate that DJs (but not PoTJs) are consistently associated with different parameters of oculomotor activity, more research is needed to replicate this finding and to interpret the kinematics of eye movements in a meaningful way within the theoretical framework of the embodied time. While FDs concern the temporal dynamic of (eye) movement (i.e., the rate at which viewers shift their gaze), saccadic amplitudes reflect the distance traveled by the eye between two fixation points. So far, studies on embodied time have considered the temporal pattern of sensorimotor changes as most relevant for time perception (Fernandes and Garcia-Marques, 2019; Meissner & Wittmann, 2011; Wackermann et al., 2014).

The implications of this study are twofold. On the one side – by employing experimental cognitive psychology methods − the study contributes to the understanding of how cinematographic techniques can influence viewers' time experience. On the other, using edited moving images as experimental stimuli contributes to the understanding of the relationships between movement (both performed and observed) and time perception.

Some limitations bear noting. First, it should be noted from our sample that the percentage of female participants was higher than that of male participants, thus limiting the generalizability of our results.

Second, although our manipulation of editing was primarily intended to alter editing density (i.e., the number of cuts), it affected other dimensions of the cinematographic language, such as editing style, amount of information on the screen, image motion (or flicker, Smith and Mital, 2013), and angle of shots. In this regard, however, it bears noting that it is hard to modify the number of cuts without affecting other cinematographic language elements in some way. For instance, the amount of information on screen does not change if the size of the shots remains the same – but, for this to happen and for cuts to remain noticeable, the angle of the shots needs to be changed. One may object that it would have been possible to simply close-up progressively on the actor. Nonetheless, close-up would have affected the amount of information on the screen (and turned out quite weird in terms of cinematographic conventions). In the light of the above considerations, the stimuli used in this study were created trying to maintain density as the main and most prominent variation, while reducing as much as possible other derivative modifications. Nonetheless, we cannot exclude that these modifications could be a confounding driving factor behind our results.

Third, although the effect of editing density on time perception was assessed across three different routine actions in this study, the kind of action was considered a random variable only. Future research could further examine whether the effect of editing on DJs and PoTJs varies depending on the type of action. Finally, future research could examine the influence of editing density on viewers' motor areas' activity, which are also related to time perception, to deepen our understanding of the mechanisms underpinning the relationship between movement and temporal judgments.

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Footnotes

1 The so-called "continuity-editing" consists of a set of rules and editing conventions that allow the viewer to easily integrate the shots into a continuous narrative and contribute making a cut "invisible" (e.g., Bordwell and Thompson, 1983; Cutting, 2005; Magliano and Zacks, 2011; Smith et al., 2012).

2 Each action was shot twice. The first shooting comprised six angles, the second one the remaining three. The duration of the second shooting was controlled accurately by asking the actor to repeat it until the performance of the action had the same duration of the first one. Concerning the subparts of each action, the actor was trained to pace the action according to a constant rhythm, and it was assisted while performing through an external pacing cue (i.e., one of the researchers vocally pacing the action).

3 We also conducted the analyses on fixation count and total fixation duration. The results showed that editing had a significant effect on the number of fixation, $F(2, 292.32) = 117.03$, $p = .000$. Both slow-paced (mean difference = 3.60, SE = .42, $p = .000$, 95% CI: 2.59, 4.61) and fast-paced editing (mean difference = 6.65, SE = .44, $p = .000$, 95% CI: 5.60, 7.70) generated a higher number of fixations than the master-shot video clip. By contrast, no significant effect of editing was found on total fixation duration, $F(2,276.39) = .74$, $p = .480$.

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Appendix

Table 1. *Parameter Estimates and Variance Components for Fixation Mean Duration and Saccade Amplitude*

	Fixation Mean Duration		Saccade Amplitude	
	Empty Model	Tested Model	Empty Model	Tested Model
Measure/Parameter	Est (SE)	Est (SE)	Est (SE)	Est (SE)
Fixed effects				
Intercept	343.45*** (5.74)	413.36*** (25.54)	4.93*** (0.07)	5.04** (0.38)
Editing Density				
Style B	-	-65.82*** (11.47)	-	-0.25 (0.12)
Style C	-	-100.61*** (11.47)	-	-0.11 (0.13)
Variance components				
Videoclip 1 (A, 1)	69399.07*** (12457.14)	29678.51*** (5558.76)	2.49*** (0.45)	1.29*** (0.25)
Videoclip 2 (A, 2)	54001.98*** (9957.89)	20533.08*** (3906.81)	4.30*** (0.79)	3.16*** (0.62)
Videoclip 3 (A, 3)	25087.30*** (4587.82)	12306.87*** (2478.45)	4.31*** (0.81)	2.89*** (0.58)
Videoclip 4 (B, 1)	23400.98*** (4180.22)	7931.31*** (1593.18)	2.52*** (0.48)	0.86*** (0.27)
Videoclip 5 (B, 2)	21901.60*** (4034.15)	8494.37*** (1732.53)	2.12*** (0.41)	1.22*** (0.29)
Videoclip 6 (B, 3)	12569.60*** (2344.35)	3273.50*** (784.05)	3.26*** (0.61)	1.45*** (0.32)
Videoclip 7 (C, 1)	8446.16*** (1564.59)	3297.31*** (813.63)	1.08*** (0.20)	0.53*** (0.16)
Videoclip 8 (C, 2)	12274.39*** (2265.25)	5265.77*** (1127.95)	2.11*** (0.40)	0.69*** (0.18)
Videoclip 9 (C, 3)	16441.18*** (3025.14)	6578.37*** (1381.58)	2.33*** (0.43)	0.71*** (0.15)
Subject (Intercept)	-	9768.16*** (1920.07)	-	1.11*** (0.22)
Type of action (Variance)	-	1195.80 (1237.79)	-	0.33 (0.34)
Deviance statistic (-2LL)	7008.51	6643.41	2010.75	1760-.96
AIC	7026.51	6665.42	2028.75	1782.96
df	10	17	10	17

Note: *** $p < .001$; ** $p < .01$; * $p < .05$. The estimates reported in this table were obtained using editing A (master-shot) as reference condition. A = Master-shot, B = Slow-paced editing, C = Fast-paced editing. 1 = Drinking water, 2 = Cutting bread, 3 = Moving objects.

Table 2. *Parameter Estimates and Variance Components for Time Perception.*

	Subjective Judgment		Duration Estimate	
	Empty Model	Tested Model	Empty Model	Tested Model
Measure/Parameter	Est (SE)	Est (SE)	Est (SE)	Est (SE)
Fixed effects				
Intercept	5.50^{***} (.07)	5.25^{***} (.16)	1.12^{***} (.017)	1.10^{***} (.08)
Editing Density				
Style B	-	.15 (.12)	-	$.06^{*}$ (.03)
Style C	-	$.55^{***}$ (.13)	-	$.07^{**}$ (.03)
Variance components				
Videoclip 1 (A, 1)	3.25^{***} (.58)	1.45^{***} (.30)	$.16^{***}$ (.03)	$.04^{***}$ (.01)
Videoclip 2 (A, 2)	2.53^{***} (.46)	1.37^{***} (.29)	$.14^{***}$ (.03)	$.05^{***}$ (.01)
Videoclip 3 (A, 3)	2.50^{***} (.46)	0.99^{***} (.21)	$.16^{***}$ (.03)	$.05^{***}$ (.01)
Videoclip 4 (B, 1)	1.92^{***} (.34)	1.04^{***} (.22)	$.17^{***}$ (.03)	$.05^{***}$ (.01)
Videoclip 5 (B, 2)	2.44^{***} (.44)	1.05^{***} (.22)	$.21^{***}$ (.04)	$.07^{***}$ (.01)
Videoclip 6 (B, 3)	2.88^{***} (.53)	1.53^{***} (.31)	$.34^{***}$ (.06)	$.11^{***}$ (.02)
Videoclip 7 (C, 1)	2.47^{***} (.45)	1.92^{***} (.38)	$.18^{***}$ (.03)	$.06^{***}$ (.01)
Videoclip 8 (C, 2)	2.36^{***} (.44)	1.71^{***} (.34)	$.31^{***}$ (.06)	$.11^{***}$ (.02)
Videoclip 9 (C, 3)	2.70^{***} (.49)	1.54^{***} (.31)	$.27^{***}$ (.05)	$.08^{***}$ (.02)
Subject (Intercept)	-	1.15^{***} (.23)	-	$.13^{***}$ (.01)
Type of action (Variance)	-	.01 (.01)	-	.01 (.01)
Deviance statistic (-2LL)	2072.54	1872.17	700.54	281.63
AIC	2090.54	1894.17	718.54	303.63
df	10	17	10	17

Note: *** $p < .001$; ** $p < .01$; * $p < .05$. The estimates reported in this table were obtained using editing A (master-shot) as reference condition. A = Master-shot, B = Slow-paced editing, C = Fast-paced editing. 1 = Drinking water, 2 = Cutting bread, 3 = Moving objects.