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Subliminal Stimuli Generated in Films through Successive Frames: A Quantitative Assessment

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Abstract

Although numerous theoretical references have been made to subliminal stimuli in filmmaking, no quantitative studies to date have sought to specify their temporal limits. Since the 1920s, several filmmakers have aimed to elicit an emotional impact on the viewer through the inclusion of isolated frames, which supposes the minimum possible temporal extension in films. Through two experiments, this study analysed the threshold between subliminal and supraliminal stimuli in films containing potential subliminal stimuli comprising one to four frames, played at frame rates of 25, 30, and 60 frames per second. The first experiment involved asking participants to view a film excerpt, including these stimuli, and then answer a survey. The second required participants to identify potentially subliminal stimuli whilst viewing a film clip. The stimuli analysed could not be defined as subliminal for 100% of viewers for any number of frames per frame rate, but were predominantly unidentified for one-frame stimuli in films played at 24 or 30 frames per second, and one- to three-frame stimuli in films played at 60 frames per second. Furthermore, three- and four-frame stimuli at 24 and 30 frames per second were found to be supraliminal, whilst the results for two-frame stimuli played at 24 or 30 and four-frame stimuli played at 60 frames per second were inconclusive. Future research is needed to analyse the effect of the nature of the image used as a stimulus and its location within a shot or in a cut between shots.

Keywords

film, frame, objective threshold, spectator, subliminal, subjective threshold, threshold, supraliminal

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1. Introduction

Narrative absorption refers to a film's immersive capacity which increases the spectator's focus of attention and reduces the extent to which they are self-conscious (Kuijpers *et al.*, 2021; Tan *et al.*, 2017). This situation gives rise to the aesthetic illusion (Wolf, 2004), creating a state of mind that allows the illusion-creating fiction of the viewer to become invested in the content of a fictional story through embodied, cognitive, and emotional processes (Kuijpers *et al.*, 2021). According to the Event Indexing Model (Magliano *et al.*, 2001) and the Event Comprehension Theory applied to visual narratives (Loschky *et al.*, 2020), spectators generate cognitive models whilst watching a film. These mental models are continuously updated following the identification of changes in story entities and the event models. This process depends on the relationship between the use of top-down schemes for scene comprehension and bottom-up processing of the stimulus features (Bordwell, 1991; Tan, 2018). Framing, editing and sound define the spectator's top-down target stimulus search. In particular, it is crucial to maintain a smooth development of events along the narrative, especially when cuts appear, in order to enhance the absorption experience during the viewing of the film. These mental schemes are critical for understanding sequences of non-overlapping cuts.

Within this theoretical framework, the apparition of subliminal stimuli in the photogrammatic chain acts as an aggressive intruder. These stimuli are designed to be included in the frame flow, but not to be perceived. The fact that spectators perceive these kinds of stimuli as threatening to narrative absorption, if they are potentially included in the story entities and events, raises the risk of erroneous narrative integration which implies the breakage of the aesthetic illusion. This scenario necessitates that editors be extremely precise when using subliminal stimuli in films.

Emotions aroused by a subliminal stimulus should be classified as aesthetic emotions, clearly differentiating them from emotional responses to witnessed events. These kinds of emotions are produced due to characteristics of the artefact such as the style or use of technology (Tan, 2018). During absorbed film viewing, the narrative elements of the story, as well as the designed fictional world and characters, belong to the domain of consciousness, whilst the representation of narrative cues, procedures, strategies, film style and technology are considered preconscious or subliminal (Tan *et al.*, 2017).

Among the various forms of subliminal effects that films can produce, this article is primarily concerned with the effect of a stimulus that appears on screen for only a fleeting moment. Following a shot change by cut, there is a disruption in immediately subsequent cognitive processes, delaying acquisition of awareness of the new stimulus (Shimamura *et al.*, 2015). Following a cut, the spectator's gaze requires approximately 360 to 400 ms to focus on the new stimulus (Smith *et al.*, 2012). This suggests a first approximation to the subliminal threshold because the duration of the subliminal stimuli should be shorter than the time needed to make an ocular fixation (in films, this is fewer than nine frames at 25 frames per second).

Durations under nine frames are not uncommon throughout the history of cinematographic technique. Indeed, the use of a single frame as a visual stimulus in films can be traced back to experimental films in the Soviet cinema of the 1920s. For instance, Elizaveta Svilova edited Dziga Vertov's 1929 film *Man with a Movie Camera* using this technique. The aim of such a strategy is to elicit an emotional response in the spectator beyond the standard use of the shot as a narrative element.

A stimulus is considered subliminal when it triggers low-level neural processes (Pan *et al.*, 2017) but fails to trigger the neural processes required to reach consciousness. Conversely, when enough neural processes are triggered to achieve consciousness, the stimulus is then considered supraliminal, meaning it is perceived consciously. Although a subliminal stimulus is too fleeting for a person to be conscious of its existence, it alters the neural processes triggered by the supraliminal images that follow it (Berkovitch and Dehaene, 2019; Yang *et al.*, 2011). The mask-triggered inhibition hypothesis postulates that the stimulus subsequent to a subliminal stimulus, referred to as a mask, inhibits the development of prior neural processes before they reach consciousness. This results in a pattern of neural behaviour fit for processing only those stimuli that are useful for our relationship with the environment (Jaśkowski and Przekoracka-Krawczyk, 2005). Some researchers posit that the cognitive system identifies the mask stimulus as an information update (Schlaghecken and Eimer, 2004), which means that the neural processes that have already been triggered are not discarded, but adapted to the new perception.

Research on the effect of subliminal stimuli on posterior supraliminal stimuli has led to the formulation of cognitive models in which neural responses are not initiated by the perception of the stimulus itself, but modulated continuously over time (Parkinson and Haggard, 2014), permitting a flow adapted to and optimised for a continuous reality. Conversely, other theories suggest that the relationship established between the subliminal stimulus and the one immediately following it are processed in terms of a conflict of perception, whereby the influence exerted by the subliminal image becomes a manifestation of the resolution of the conflict (Boy *et al.*, 2010). This proposal is conceptually aligned with theoretical principles of Soviet cinema based on *collision editing* and *counterpoint* (Eisenstein, 1977). According to this theoretical proposal, combining synthesis with its antithesis through film editing produces a new synthesis. This suggests that the juxtaposition of shots with antithetical intentions generates meaning for the viewer. Even the concept of mere exposure seems to have an effect on stimuli shown for durations under 200 ms (Monahan *et al.*, 2000). The concept of mere exposure is based on the fact that repeated exposure to a stimulus increases the probability that it will be evaluated positively (Nanay, 2017).

However, just because a subject will be exposed to a stimulus for a fleeting moment without reaching consciousness does not necessarily mean that it should be considered subliminal. Cheesman and Merikle (1984) defined the concepts of *objective threshold* and *subjective threshold* in order to distinguish between what could be considered subliminal and what could not.

The objective threshold is defined as the point where low-level processes are triggered without reaching consciousness, whereas the subjective threshold is the point at which the stimulus has been perceived consciously and can therefore be considered supraliminal (Fig. 1). Between the objective and subjective thresholds, participants consider themselves unable to discriminate perceptual information beyond a chance level, whereas if the objective threshold is not reached, the participants are not even able to discriminate perceptual information at a chance level (Cheesman and Merikle, 1984). Depending on the previous and subsequent context and the characteristics of the stimulus itself, it is estimated that the subjective threshold is located somewhere within the range of 32 to 80 ms (Armstrong and Dienes, 2013). The subjective threshold is also believed to be between 30 ms and 50 ms longer than the objective threshold (Cheesman and Merikle, 1984).

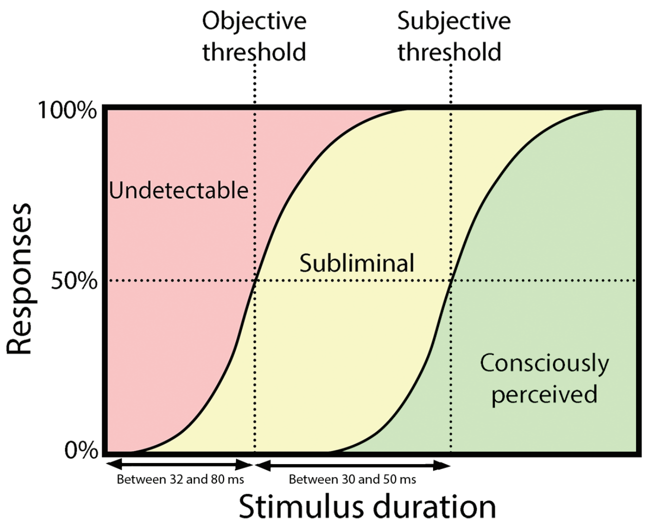

Figure 1. Scheme of the subliminal condition bounded by objective and subjective threshold estimations.

In conceptual short-term memory, the perceived stimuli are categorised at a meaningful level, activating relationships with long-term memory and structuring the information received (Potter, 2012). Any information that is not structured or consolidated is forgotten without entering the conscious mind. A common way to analyse the conceptual short-term memory with visual stimuli is to limit the processing time of the stimulus by inhibiting consolidation processing with a visual mask. Rapid serial visual processing (RSVP) has been shown to be highly effective in analysing this process (Coltheart, 1999; Potter, 2012).

The RSVP paradigm consists of presenting the participants with a continuous stream of images (all with the same duration), including a target image that stands out among the others (Manor and Geva, 2015). Previous research has confirmed that fast presentation rates limit visual processing compared with slower presentations (Grootswagers *et al.*, 2019). RSVP-based experiments have also revealed that participants begin missing target stimuli with presentation times under 125 ms (Wang *et al.*, 2016), reflecting processing deficits. Recognition memory is relatively poor for presentations between 100 and 300 ms (Potter *et al.*, 2002). These results are consistent with EEG-based experiments which have confirmed that backward pattern masking influences the processing of the target stimuli for durations shorter than 180 ms (Fahrenfort *et al.*, 2007).

Although experimental strategies focusing on the subliminal image (based on the mask-triggered inhibition hypothesis) and those based on RSVP are both oriented towards analysing cognitive processes in situations of short duration, crucial differences exist between them. Most notably, the visual information processed depends on the proportion of stimuli that must be correctly consolidated in a short time (Ricker and Hardman, 2017). Because it is not possible to process more than one image in a short period of time (Robinson *et al.*, 2019), the presentation of multiple images in quick succession may trigger a competition and/or interruption (Keysers and Perrett, 2002). This can make the consolidation of visual stimuli in RSVP less effective compared with other experimental paradigms where the target stimulus is present for a short time and the stimuli before and after are present for longer durations (e.g., masked priming paradigm).

One of the main challenges of such experiments is how to measure consciousness. The different types of consciousness measures are classified into direct and indirect, and objective and subjective (Timmermans and Cleeremans, 2015). Objective types of measurement are aimed at detecting effects without having reached a reportable level of consciousness, with indirect measures targeting priming effects and direct measures assessing no conscious awareness of the masked stimuli (Zerweck *et al.*, 2021) or the effects of forced-choice discrimination (Timmermans and Cleeremans, 2015). The subjective direct criterion is based on detected unconscious perception when participants report that they have not perceived the target stimuli, as well as evaluating their confidence judgements. The indirect criterion involves analysing whether participants are unable to perform a related task with results better than chance or exceeding their metacognitive judgement (Szczepanowski and Pessoa, 2007; Timmermans and Cleeremans, 2015).

The inclusion of isolated frames in films dates from the 1920s to the present. However, although extensive research has been conducted on subliminal stimulation, this question has received little attention in the field of film studies, especially in research adopting a quantitative approach. Furthermore, in the few studies that do exist in this field, shots that are clearly visible to spectators have sometimes been defined as subliminal stimuli (e.g., Friday, 2003; Salpeter and Swirsky, 2011). To avoid possible confusion, it is necessary to establish a temporal threshold that will allow researchers to objectively discern what can be considered subliminal and what cannot. Whilst there has been an abundance of research on the temporal limits of perception in experimental psychology, no quantitative research has been conducted on this question in the field of film studies.

In a film, the reproduction frequency of frames per second (fps) determines the temporality that a stimulus can represent. For this reason, it is common for both technical manuals (Marimón, 2015) and research reports (Smith *et al.*, 2012) that aim to define temporal aspects with precision in the film industry to analyse temporality in terms of the number of frames, usually at the most common projection frequency of 24 or 25 fps.

Given all these considerations, the aim of this study was therefore to establish an objective quantification of the number of frames that a stimulus in a film requires to be classified as subliminal. This will make it possible to distinguish between what is subliminal and what is not, which may be of value to film directors and editors interested in incorporating subliminal stimuli as a narrative enhancement strategy.

2. Methods and Materials

To establish the number of frames that a stimulus in a film requires to be described as subliminal, two different experiments were designed. Experiment 1 required participants to watch three different film excerpts with four potential subliminal stimuli inserted in each one. After viewing each film excerpt, participants responded to an image recognition survey to report whether they had seen the subliminal stimuli. In Experiment 2, participants were tasked with detecting and identifying a specific image among different potential subliminal stimuli within a film excerpt. In both cases, the experimental videos were of different frame rates (24, 30, or 60 fps) and the stimuli were of different durations (from one to four frames).

Furthermore, in both experiments, the requirement for participants was not limited to detection (absence/presence) as identification was also demanded. This differentiation is important because correct identification implies a conscious perception of the stimulus. There are several experiments in the subliminal field that differentiate between detection threshold and identification threshold, conceptualising identification as a way of defining supraliminal perception (Beauny *et al.*, 2020; Núñez and de Vicente, 2004).

Numerous studies have indicated that the awareness process is not a dichotomous succession of states, but rather involves a gradual process (Overgaard *et al.*, 2006; Sandberg *et al.*, 2011). In this gradual process, identification is possible without the need for absolute awareness of the image; instead, it is sufficient for there to be awareness of sufficient features of the stimulus that allow its identification. However, there is a clear difference between the detection task, which merely requires awareness of the stimulus's presence, and the identification task where the identification task initiates conscious recognition processes.

Furthermore, analysing films requires that this differentiation be taken into consideration, as identifiable stimuli construct the narrative of the film as being potentially capable of updating the story entities and event models, whereas those that are not identifiable do not (Tan *et al.*, 2017).

For the statistical analysis, a generalised linear mixed model (GLMM) was utilised for Experiment 1, and a generalised linear model (GLM) was employed for Experiment 2. This distinction arises from the nature of the data in Experiment 1, which includes measurements that may be influenced by previous observations from each participant, potentially compromising the independence of identification samples. Consequently, the data were statistically considered to contain repeated measurements. Additionally, for all variables identified as statistically reliable, a pairwise analysis was performed. Following this, a descriptive analysis was undertaken on the percentages of stimuli identified in Experiment 1 (direct objective criterion) and the percentages of missed identifications in Experiment 2 (direct objective criterion).

2.1 Participants

The participants in the two experiments were drawn mainly from the Faculty of Philology and Communication at the University of Barcelona (students, professors, and administrative staff). Of the 99 participants finally recruited, 69.7% were women and 30.3% were men. The average age of the participants was 26.2 years, with a mode and median of 22 years. The youngest participant was 18 and the oldest was 63. All participants previously reported having normal or corrected-to-normal vision.

The participants performed the two experiments in succession, although they were required to move to another room to conduct the second experiment. Firstly, they completed Experiment 1, then Experiment 2. Although a total of 96 participants were initially recruited for the experiments, five participants decided not to conduct Experiment 2 after completing Experiment 1. Consequently, three additional participants were recruited to conduct Experiment 2 only, completing the sample for this second experiment (94 participants).

In both experiments, 72 participants performed the experiment under normal conditions, with 24 allocated to each group (frame rates: 24, 30, and 60 fps). This was based on the sample size criterion for experiments in other studies that explored mask-triggered inhibition (Bermeitinger and Wentura, 2016; Wang *et al.*, 2018). The remaining participants were allocated to the control group for each experiment (24 for Experiment 1 and 22 for Experiment 2).

2.2. *Film Excerpts*

Different film excerpts were used for the experiments, and were played at frequencies of 24, 30, and 60 fps. The frame rates chosen for both experiments represent the most common rates used in the film industry. Specifically, 24 fps is the standard for theatrical exhibition, Blu-ray, and VoD platforms; 30 fps was included because it is the National Television System Committee (NTSC) standard used for broadcast TV in the United States; and 60 fps was a minority frame rate for Blu-ray, but continues to be used today for VoD platforms. Although 25 fps is also an important frame rate due to its use as the Phase Alternating Line (PAL) standard, it was not used because it is too close to 24 fps. The excerpts were extracted from films at their original frame rate; no frequency conversion was performed in the extraction process.

The films from which fragments were extracted for the experiments were *All the Money in the World* (Ridley Scott, 2017), *I, Tonya* (Craig Gillespie, 2017), and *Unbreakable* (M. Night Shyamalan, 2000) due to their availability in the three different formats.

Although the original frame rates of materials marketed to the public for audiovisual consumption were considered for the experimental design, it was not possible to conduct the filming in all formats. This means there was only one original frame rate, and that the other two possibilities were both the result of professional conversions.

The raw footage in all three films was shot at 24 fps which is the most common, as it is required in movie theatres around the world. It could be deduced that the original material was shot at 24 fps because, when the material was analysed at 30 fps, one frame was observed to be duplicated every five frames. This occurs because converting the sample rate from 24 to 30 fps requires adding six frames every second to ensure that the audio remains unchanged. If the original material had been filmed at 30 or 60 fps, no frames would be repeated at 30 fps, as this would be the original material or it would be a direct divider. Thus, from material filmed at 60 fps, it would be enough to eliminate one frame every two frames and the conversion would not be visually noticeable.

In the example in Fig. 2, a total equivalence can be observed between frames 1-A and 2-A, 1-B, 2-B and 2-C, 1-C and 2-D, and 1-D and 2-E. This is because frame 2-C is the duplication of 2-B (being the same as 1-B), and is used to transfer the original material from 24 fps to 30 fps.

It is also possible to infer that the original material was not filmed at 60 fps, but at a lower frequency because of the need to generate intermediate frames to maintain the duration of the soundtrack. In this case, the frame duplication system is not used because numerous repeated frames would be needed. For instance, converting from a 30 fps source material to 60 fps duplicating frames would appear to be the same as playing at 30 fps with a 60 Hz screen refresh rate. Therefore, the most common method for converting to 60 fps is the frame-blending technique which involves computationally inferring intermediate frames from the original frames. It is common to use a 30 fps version as the source material for converting to 60 fps, as the interpolation process is easiest when using source materials with frame rates that are divisors of the target frame rate. Typically, this technique introduces minor errors into the inferred frames, which are detectable visually upon detailed analysis.

To determine whether the original material has been shot in 30 or 60 frames, a frame-by-frame comparison between both films is required. If it was shot at 30 fps, interpolation errors can be detected in the 60 fps version. If it was shot as 60 frames, for each of the two frames with an exact frequency, one would have to exactly match the 30 fps material.

Figure 2. Fragments of five frames belonging to the movie *All the Money in the World,* in which it is possible to appreciate the frame rate transformation from 24 frames per second (fps) through frame duplication at 30 fps and through frame blending at 60 fps.

In Fig. 2, frames 3-B and 3-C are the same, so it can be deduced that the transformation has been made from the 30 fps version, as it would correspond to interpolations from the duplicated frames of 2-B and 2-C. However, we can see errors in some small details due to interpolation in frames 3-A and 3-D. For example, in the 3-A frame, there is an error in the sticker that appears inside the cabin above the character's head, and in the 3-D frame, errors appear on the character's face closest to the door, in their hair, their eye, and on their chin.

However, despite these limitations, it was deemed preferable to use films with commercial versions at 24, 30, and 60 fps for the experiment rather than to create our own conversions. The frame rate of these films was generated using professional systems from a higher-quality source, and they have been marketed at those specific frame rates. These conditions consistently produce better audiovisual material than conversions made expressly for experimental purposes. Therefore, the only manipulation of the material consisted of selecting specific fragments at different frame rates and including potentially subliminal stimuli.

Given the three different frame rates, both experiments were designed to evaluate potentially subliminal stimuli present in one, two, three or four consecutive frames embedded in the excerpts. Four frames were considered a suitable maximum length for 24 fps and 30 fps (four frames at 24 fps = 166.67 ms; five frames at 24 fps = 208.33 ms) because experiments based on RSVP consider 180 ms to be the threshold at which no perceptual problems arise due to temporal insufficiency (Fahrenfort *et al.*, 2007).

There is evidence to suggest that the potential influence of subliminal stimuli and the time needed to reach consciousness may be associated with the formal structure of the images proposed for the stimuli, that is, depending on whether they are faces, geometric patterns, or colour tones (Lai *et al.*, 2020; Milner and Goodale, 2006; Yang *et al.*, 2011). For this reason, four very different images were used as potential subliminal stimuli (Fig. 3).

These four images (Fig. 3) were chosen because they were all used as stimuli with a subliminal intention in the films from which they were taken. These images were embedded in their original films as single frames. In their original context, they were presented as isolated frames, except in the case of *Se7en* where the frame was repeated twice, forming a two-frame stimulus. During

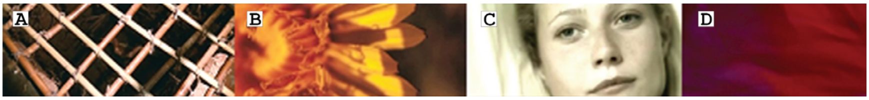

Figure 3. Images embedded in the videos to serve as potentially subliminal stimuli: (A) *First Blood* (Orion Pictures, 1982); (B) *In the Earth* (Neon, 2021); (C) *Se7en* (New Line Cinema, 1995); and (D) *The Thin Red Line* (20th Century Fox, 1998).

the experiment, film excerpts were shown to the participants with the original audio. To preserve the integrity of the original audio track, any potentially subliminal stimuli embedded in the excerpts replaced an equal number of frames from the original footage.

2.3. Ethics

The entire experimental process and the management of data adhered to the *Code of Good Research Practices* of the University of Barcelona and the *European Code of Conduct for Research Integrity*. The University of Barcelona's Bioethics Commission (CBUB) issued the certificate authorising the study (IRB00003099). All participants were informed of the experiment verbally and in writing, and all signed the required consent document.

Participation was entirely voluntary. The data in the experiment were always anonymised, thereby ensuring there was no possible way to relate the informed consent document containing personal data to the data collected in the experiment, which were indexed by means of a numerical identifier.

3. Experiment 1: Viewing without Task

3.1. Methods

The design for Experiment 1 was adapted from the staircase psychometric method (Beauny *et al.*, 2020). Staircase methods aim to identify perceptual thresholds by presenting a series of stimuli of different durations to the participant in the experiment (Leek, 2001), specifically to differentiate between subliminal and supraliminal stimuli (Beauny *et al.*, 2020). To locate the perceptual threshold, the duration of the stimulus is progressively increased (increasing staircase) or decreased (decreasing staircase) and the results are compared with a sigmoidal, exponential, or logarithmic function. The difference between the staircase procedure and the one applied in the present research was that the original procedure tracked the thresholds by increasing or reducing the stimulus duration according to the participant's response. In the present research, the increased or decreased duration of the stimulus was not adaptative, as in the method of constant stimuli; instead, the stimulus duration was ordered in an incremental constant progression rather than a random order (Kingdom and Prins, 2010). Another difference is that in the staircase procedure, the detection, discrimination or identification of the stimuli usually happens immediately after, and the participant typically watches only one stimulus before the task request, whereas in the present study, the participant watched four stimuli before answering. This means that, in addition to subliminal stimuli, the unidentified stimuli will also relate to no consolidated memories, although both cases indicate that the stimuli were not assimilated or integrated into the story entities or in the event models. This possibility is defined as the immediacy criterion which implies possible distortions in the results due to forgotten or information interferences affecting the participant (Newell and Shanks, 2014; Timmermans and Cleeremans, 2015).

In this study, Experiment 1 was designed to delay the moment when participants became aware of the objective of the experiment as much as possible, so that their attention was modified as little as possible by the identification of the potentially subliminal stimuli. The experiment adhered to the direct objective criterion, based on the reported awareness of the participants through free-choice identification.

Three film excerpts were prepared for the experiment, taken from the films *All the Money in the World* (3′38″), *I, Tonya* (3′44″) and *Unbreakable* (5′11″). The four potentially subliminal stimuli inserted into the film excerpts (see Fig. 3) were separated by intervals ranging from 30″ to 1′, depending on the duration of the excerpt and the location of the shot changes. These stimuli were arranged in ascending order from one to four frames. Thus, the first excerpt contained two one-frame stimuli followed by two two-frame stimuli, while the second excerpt contained two two-frame stimuli followed by two three-frame stimuli; the third excerpt contained two three-frame stimuli followed by two four-frame stimuli. An example of the audiovisual material used is accessible via the OSF repository (see Supplementary Material).

The second and third film excerpts began with potentially subliminal stimuli of the same duration as the last stimuli in the previous excerpt. This strategy proved useful for confirming whether variations in participants' perception occurred as a result of viewing the previous video and completing the survey.

The order in which the four images were inserted was not repeated in the three video clips viewed by each participant and no image was shown twice in the same video. The order of the inserted images was altered randomly for each film clip; however, according to a count taken at the end of the experiment of all the clips shown, all the images appeared the same number of times in each position of the video for each excerpt and duration.

In the clips from *All the Money in the World* and *I, Tonya*, the potentially subliminal stimuli were inserted at editing cuts, whilst in *Unbreakable* they were inserted into moments of internal development of a shot. The three videos were shown in random order, and none was repeated for the same participant. Similarly, the order in which the videos were shown was recorded for all participants in order to ensure that the three excerpts were viewed the same number of times in first, second, and third place.

The three videos shown to participants were played at 24 fps, 30 fps, or 60 fps, but each participant was shown all three videos at the same frame rate to ensure that the clips were shown the same number of times at each frame rate.

After viewing each film excerpt, participants were given a survey requiring them to select the images they had perceived whilst viewing. This survey (which can be accessed via the OSF repository — see Supplementary Material) included four images from each film excerpt (12 non-subliminal targets), the four target images used as potentially subliminal stimuli (Fig. 3), and eight images extracted from films that had not been used for the experimental excerpts (distractors): two from *First Blood* (Ted Kotcheff, 1982), three from *In the Earth* (Ben Wheatley, 2021), one from *Se7en* (David Fincher, 1995), one from *The Thin Red Line* (Terrence Malick, 1998), and one from *Sunshine* (Danny Boyle, 2007). In total, the survey contained 24 images. This experiment was conducted by screening the excerpts with pairs of participants. The projector used for the screening was an Epson EB-485W, adaptable to refresh rates of 24, 30, 50, and 60 Hz. The distance between the participants and the screen was 3 m, and the screen dimensions were 1.9×1.1 m.

The sessions designed to obtain control results involved the use of a clip showing the original film excerpt with no potentially subliminal stimuli, and a second and third video clip with potentially subliminal stimuli but, in this case, the order of the constant progression design was altered. Consequently, the stimuli included in the second video consisted of two and three frames, whilst in the third they were one and two frames. All three videos used to obtain control results were shown at a frame rate of 24 fps, as this is assumed to be the classical standard for film projection.

The viewing of the first video in the control sessions helped to identify potential errors (unrelated to the insertion of potentially subliminal stimuli) committed by participants when completing the surveys. It should also be noted that potentially subliminal images acted as distractors in the identification survey during this first viewing. In the viewing of the second and third videos in the control sessions, the purpose of altering the order of the constant progression design was to address the variations resulting from the alteration of only one constant throughout the experiment, which is the progressively increasing duration of the potentially subliminal stimuli.

3.1.1. Statistical Analysis

In Experiment 1, the GLMM was used to analyse participants' responses to each stimulus as identified or unidentified with a binomial link function (binary probit). The analysis counted responses for the same number of frames as repeated measurements as the perception of each one can modify the perception of the next. The fixed effects analysed were (i) the specific image of the stimulus, (ii) whether the stimulus was inserted within a shot or between shots, (iii) the interaction between the number of frames and frame rate (two-way interaction), and (iv) the interaction between sequence position, number of frames, and frame rate (three-way interaction). Stimuli of the same number of frames (iii) were not necessarily of the same duration (e.g., one frame = 41.67 ms at 24 fps and 16.67 ms at 60 fps). Thus, the fixed effect of duration required two factors (number of frames*frame rate). To define the fixed factor related to the sequence position (iv), it was important to take into account the fact that the same number of samples of each number of frames differed (e.g., two one-frame stimuli and four two-frame stimuli). Therefore, the definition of this fixed factor depends on two factors for sequence position and one further factor to differentiate the frame rate effect (sequence position*number of frames*frame rate). The three different film excerpts (*All the Money in the World*, *Unbreakable,* and *I, Tonya*) and participants were classified as random effects applied to intercepts. The relevance of the fixed effects was evaluated by means of an *F* test. A pairwise comparison with a sequentially step-down rejective Šidák procedure (Agbangba *et al.*, 2024; Šidák, 1967) was also applied to each fixed effect.

The identification of images in the questionnaire was not a forced-choice task, so the identification of potentially subliminal stimuli that had not reached the participants' consciousness should be close to 0%. By analysing the control group that watched the video without potentially subliminal stimuli, it was possible to calculate the dispersion of results due to mismatch identification. This calculation was based on the number of times that the control group participants identified in the questionnaire images that had not appeared in the film excerpts viewed. The dispersion of these mistakes was used as a reference to determine the threshold that can be considered statistically relevant for non-identification.

By performing a frequency analysis using the *z* test, it was possible to determine whether there was a relevant deviation from non-identification by adding the mismatch identification dispersion value to 0, which signifies the total absence of identification in all participants for all stimuli included due to a lack of awareness of the presented stimuli. However, it is possible that this lack of awareness did not occur in every case but in a large number of them, so this system was adapted to the likelihood distribution obtained by posterior distribution characterisation for binomial inference based on the initial belief that identification success was 0 for each frame rate and number of frames. This Bayesian strategy was based on an initial belief in adjusting the probability of the event according to the samples analysed.

3.2. Analysis of Results

Prior to analysing the results for Experiment 1, it was important to check for possible distortions due to the nature of the procedure. To this end, the results for the experimental group and the control were compared. Pairwise comparisons between the experimental group and the control group can be accessed in the OSF repository (see Supplementary Material).

The lowest *t test p*-values appeared when comparing one-frame stimuli in the same positions between the experimental group and the control group (first: $t_{46} = 1.497$, $p = 0.146$; second: $t_{46} = 2.436$, $p = 0.019$). This could be an indication that when one-frame stimuli appeared in a second video after a first video with two- and three-frame stimuli, the possibility of identifications increased, confirming the suspicion that participants' attention was modified during the experiment. In addition, a pairwise comparison between the experimental group and the control group also revealed no statistically reliable differences ($0.182 \leq p \leq 0.391$) between the experimental group (with potentially subliminal stimuli) and the control group (without potentially subliminal stimuli) in terms of identifying non-subliminal target images in the image identification questionnaire (first video shown in control group session).

It is also relevant to emphasise that, in the control group, the mistakes made in the first questionnaire were related to not having identified frames that appeared in the videos observed and never selecting frames that had not been shown in the videos. This fact, given that none of the questionnaires required a forced choice, eliminates the possibility that the participants mistakenly marked the inserted frames added during the experiment.

To analyse the results of Experiment 1, the first point to consider was the percentage of potentially subliminal stimuli identified by aggregating all participants' identifications of the inserted frames for each number of frames. These results are presented in Fig. 4 where the two-frame stimuli in the first and second videos are presented as averages (2-frame-A and 2-frame-B), as are the three-frame stimuli for the third and fourth videos (3-frame-A and 3-frame-B).

The percentage of single-frame stimuli identified at 24 fps (Fig. 4) was 27.08%, which increased progressively until it reached 93.75% for four-frame stimuli. Between the end of Video 1 (2-frame-A) and the beginning of Video 2 (2-frame-B) at 24 fps, there was no evidence to suggest that the development of the experiment impacted participants' attention and their identification capacity (45.83% in both cases); however, there was an indication that this occurred between the end of Video 2 and the beginning of Video 3 for 3-frame-A (75%) and for 3-frame-B (85.42%). The identification level for one-frame stimuli was relatively low (27.08%), whilst for two-frame stimuli, the proportion was higher (45.83%).

As noted previously, the identification of images in the questionnaire was not a forced-choice task, so detecting when potentially subliminal stimuli had not reached the participants' awareness for the same number of frames, and the identification rate should be close to 0%. According to the analyses of the

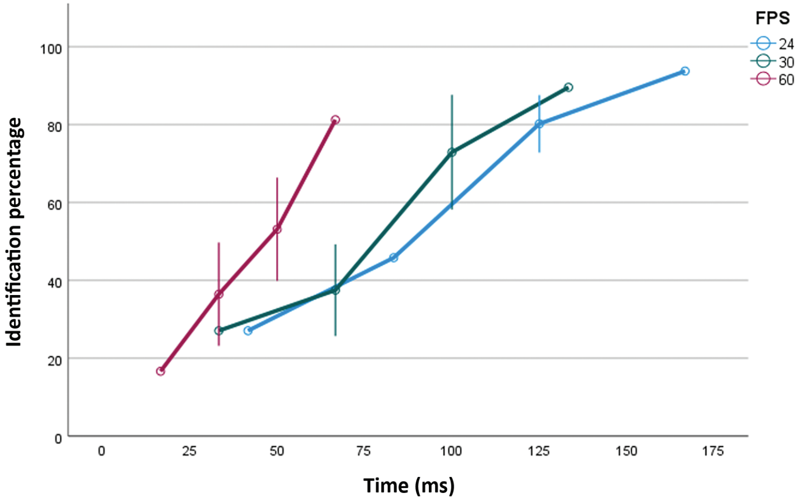

Figure 4. Time distribution of the percentages of identified stimuli in Experiment 1 for 24 frames per second (fps), 30 fps, and 60 fps. Data aggregated across participants were averaged when there were two measurements for the same number of frames (2- and three-frame stimuli). Error bars represent the averaged data's one-time standard deviation.

control group watching the video without potentially subliminal stimuli, there was no dispersion in the results due to mismatch identifications because no participant identified images that did not appear during viewing. A z test was then performed to determine whether there was a significant deviation from 0. For all durations, a statistically relevant difference was found (one-frame: $z = 58.14$, $p < 0.001$; two-frame: $z = 141.77$, $p < 0.001$; three-frame: $z = 248.33$, $p < 0.001$; four-frame: $z = 205.08$, $p < 0.001$). This means that the potential subliminal stimuli included in the excerpts could not be considered subliminal for all participants.

To analyse the level of reliability with which a stimulus could be considered subliminal at 24 fps, the likelihood that the stimulus would not be identified was calculated by posterior distribution characterisation for binomial inference. For one-frame stimuli, the posterior mean was 0.271, the variance was 0.004, and the 95% credible interval (CI) for the estimated proportion had a lower bound of 0.156 and an upper bound of 0.403. The posterior mean for two-frame stimuli was 0.458, the variance was 0.003, the lower bound of the 95% CI for the estimated proportion was 0.360, and the upper bound was 0.558. The posterior mean for three-frame stimuli was 0.802 with a variance of 0.002, and the 95% CI for the estimated proportion had a lower bound of 0.717 and an upper bound of 0.875. For four-frame stimuli, the posterior mean was 0.938 with a variance of 0.001, and the 95% CI for the estimated proportion had a lower bound of 0.855 and an upper bound of 0.987.

According to these estimations, most of the one- and two-frame stimuli would not be identified (one-frame vs 27.1% identifications: $z = -0.003$, $p = 0.998$; two-frame vs 45.8% identifications: $z = 0.01$, $p = 0.995$), whereas most of the three- and four-frame stimuli would be identified (three-frame vs 80.2% identifications: $z = 0.002$, $p = 0.998$; four-frame vs 93.8% identifications: $z = -0.01$, $p = 0.989$). These results mean that if one- or two-frame stimuli at 24 fps were considered subliminal, it would not be possible to assert that they behaved in this way for all viewers. The only possible assertion would be that they mostly act as subliminal stimuli. For instance, in the case of one-frame stimuli, the probability of not being identified by viewers would be approximately 72.9% with a CI between 84.4% and 59.7% and a certainty of 95%.

The identification percentage for one-frame stimuli at 30 fps (Fig. 4) was as low (27.08%) as it was for 24 fps. The main difference can be identified in the first occasion in which the 2-frame-A stimuli was shown, as here the identification percentage was much lower at 30 fps (29.17%). However, after participants had viewed the first video and completed the survey, the level of identification of 2-frame-B stimuli at 30 fps increased dramatically (64.58%). This variability in the results obtained suggests that for this specific duration, the identification rate depended on specific conditions other than duration such as the attention of the spectator. Regarding the remaining identification percentages, these were 83.33% for 3-frame-A stimuli, 79.17% for 3-frame-B stimuli, and 89.58% for four-frame stimuli.

A z test conducted to determine the frequency of identifications with regard to 0% success revealed that the identification frequencies for one-frame stimuli ($z = 59.147$, $p < 0.001$), two-frame stimuli ($z = 145$, $p < 0.001$), three-frame stimuli ($z = 251.56$, $p < 0.001$), and four-frame stimuli ($z = 196.146$, $p < 0.001$) were statistically different. As happened for 24 fps, the potential subliminal stimuli included in the excerpts could not be considered subliminal for all participants. To assess the likelihood that the stimulus would not be identified, the posterior distribution characterisation for binomial inference was applied. For one-frame stimuli, the posterior mean was 0.271 (one-frame vs 27.1% identifications: $z = -0.003$, $p = 0.998$) with a variance of 0.004, and the 95% CI for the estimated proportion had a lower bound of 0.156 and an upper bound of 0.403. The posterior mean for two-frame stimuli was 0.469 (two-frame vs 46.9% identifications: $z = -0.005$, $p = 0.996$), with a variance of 0.003, the lower bound of the 95% CI for the estimated proportion was 0.37, and the upper bound was 0.568. For three-frame stimuli, the posterior mean was 0.813 (three-frame vs 81.3% identifications: $z = -0.01$, $p = 0.99$), the variance was 0.002, and the 95% CI for the estimated proportion had a lower bound of 0.729 and an upper bound of 0.884. The posterior mean for four-frame stimuli was 0.896 (four-frame vs 89.6% identifications: $z = -0.004$, $p = 0.997$) with a variance of 0.002, and the calculated proportion had a lower bound of 0.796 and an upper bound of 0.965 for the 95% CI.

In this case, it was important to analyse the two-frame case based on whether it was in the first or second excerpt. This was because adding this stimulus duration to the second or first fragment resulted in a statistical difference (2-frame-A: $z = -2.46$, $p = 0.014$; 2-frame-B: $z = 2.45$, $p = 0.014$). The posterior mean for two-frame stimuli in the first excerpt was 0.294 (2-frame-A vs 29.4% identifications: $z = -0.035$, $p = 0.972$), the variance was 0.004, the lower bound of the 95% CI for the estimated proportion was 0.173, and the upper bound was 0.426. For two-frame stimuli in the second excerpt, the posterior mean was 0.646 (one-frame vs 64.6% identifications: $z = -0.002$, $p = 0.998$), with a variance of 0.005, and the 95% CI for the estimated proportion had a lower bound of 0.507 and an upper bound of 0.773.

In the same way as with the stimuli shown at 24 fps, when the reproduction frequency was 30 fps it was not possible to consider one- or two-frame stimuli as subliminal for all participants. The claim should be limited to stating that they have a majority subliminal effect. Specifically, the absence of identification was estimated to be 72.9% of cases for one-frame stimuli, with a CI between 84.4% and 59.7% at a certainty of 95%. In the case of two-frame stimuli, the results were more ambiguous; in the first video, the probability that the stimulus was not identified was 70.6%, whilst in the second video, it was 35.4%.

The results for 60 fps film excerpts (Fig. 4) revealed a relatively low perception of potentially subliminal stimuli of only one (16.67%) or two frames (27.08%). Identifications of more than half of the stimuli were not achieved until the second time three-frame stimuli were shown (62.5%). Identifications of one-frame stimuli were lower than they were for these stimuli at 24 fps and 30 fps. However, 2-frame-A stimuli at 60 fps had an identification level similar to that of one-frame stimuli at 24 fps and at 30 fps. The progression of identifications at 60 fps was extremely linear and free of major fluctuations, with marked variations between excerpts possibly attributable to the attention modification of those participants who began to realise the objective of the experiment. The remaining identification percentages were 45.83% for 2-frame-B stimuli, 43.75% for 3-frame-A stimuli and 81.25% for four-frame stimuli. Figure 4 clearly illustrates the modification of participants' attention. For 24 and 30 fps, where the duration of the stimuli and their position in the three videos were equivalent, a percentage of identifications was produced that was similar to that for 60 fps, which required a greater number of videos to be viewed to achieve similar temporal durations.

Regarding an identification of 0% compared with the identification frequency obtained in the questionnaires, there was a relevant differentiation for all the durations (one-frame: $z = 36.31$, $p < 0.001$; two-frame: $z = 112.71$, $p < 0.001$; three-frame: $z = 164.37$, $p < 0.001$; four-frame: $z = 177.88$, $p < 0.001$). Again, it was not possible to consider the stimuli shown to be in any of their subliminal durations for all participants, so the likelihood of being unidentified by the participants was calculated. The posterior mean for one-frame stimuli was 0.167 (one-frame vs 16.7% identifications: $z = -0.006$, $p = 0.996$), the variance was 0.003, the lower bound of the 95% CI for the estimated proportion was 0.076, and the upper bound was 0.283. The posterior mean for two-frame stimuli was 0.365 (two-frame vs 36.5% identifications: $z = -0.01$, $p = 0.993$) with a variance of 0.002, and the calculated proportion had a lower bound of 0.272 and an upper bound of 0.463 for the 95% CI. For three-frame stimuli, the posterior mean was 0.531 (three-frame vs 53.1% identifications: $z = 0.005$, $p = 0.996$), with a variance of 0.003, and for the 95% CI, the estimated proportion had a lower bound of 0.432 and an upper bound of 0.63. For four-frame stimuli, the posterior mean was 0.813 (four-frame vs 81.3% identifications: $z = -0.01$, $p = 0.993$), the variance was 0.003, and the lower bound of the 95% CI for the estimated proportion was 0.692 and the upper bound was 0.909. In this case, analysing the two- and three-frame stimuli based on whether they were in the first or second excerpt did not reflect a statistical difference whit the corresponding posterior mean of 0.365 (2-frame-A: $z = -1.35$, $p = 0.175$; 2-frame-B: $z = 1.34$, $p = 0.179$) or 0.531 (3-frame-A: $z = -1.3$, $p = 0.194$; 3-frame-B: $z = 1.3$, $p = 0.192$).

As in the previous cases of 24 fps and 30 fps, none of the possible durations for 60 fps allows us to state that the stimuli can always be subliminal for all viewers. Again, the results imply that when considering a given duration as subliminal for 60 fps, it should be possible to secure this condition for a proportion of spectators, but not absolutely for all viewers. At 60 fps, the absence of identification was estimated to be 83.3% of cases for one-frame stimuli, with a CI between 92.4% and 71.7%, 63.5% of cases for two-frame stimuli, with a CI between 72.8% and 53.7%, and 46.9% of cases for three-frame stimuli, with a CI between 56.8% and 37%. All credible intervals were estimated with a certainty of 95%.

3.2.1. Generalised Linear Mixed Model

The statistical reliability of the differences identified in participant perceptions was evaluated by means of a GLMM. In total, 100% of the samples ($N = 864$, [24 subjects per condition × 3 different frame rates × 12 stimuli per subject]) were included in the GLMM analysis. The goodness-of-fit method selected was Log-verosimilitud-2 (3,188.587) because it was better in this case (lower value) than the corrected Akaike information criterion (3,215.037) or the Bayesian information criterion (3,275.871). The dependent value denoting identification of the stimulus (0 = unidentified, 1 = identified) had a standard error of 0.022 ($M = 0.361$, 95% CI [0.319, 0.405]). The fixed effects were identified as relevant for the two-way interaction number of frames*frame rate ($F_{11,824} = 14.657$, $p < 0.001$) and whether the stimuli were located between shots ($F_{1,824} = 41.061$, $p < 0.001$), but were not statistically reliable enough for the specific image of the stimuli ($F_{3,824} = 2.321$, $p = 0.074$) or the three-way interaction sequence position*number of frames*frame rate ($F_{24,824} = 1.277$, $p = 0.169$) which denotes the order of the stimulus. Pairwise comparisons for the number of frames for each frame rate, as well as for different frame rates for each number of frames can be accessed in the OSF repository (see Supplementary Material).

A pairwise comparison between different numbers of frames for each frame rate yielded conclusive results. The most statistically reliable differences at 24 fps and 30 fps ($p < 0.001$) appeared between one-frame and three- or four-frame stimuli, and between two-frame and three- or four-frame stimuli. The results also reflected statistically reliable low differences ($0.001 < p < 0.05$) between one-frame and two-frame stimuli in both cases and between three-frame and four-frame stimuli at 24 fps. These results reflect a clear difference between one- or two-frame stimuli and three- or four-frame stimuli, but a less clear difference between one- and two-frame stimuli. At 60 fps, the result was $p < 0.02$ for any case. The greatest statistical reliability ($p < 0.001$) was found between one-frame and three- or four-frame stimuli and between two- and four-frame stimuli. Furthermore, there was also a statistically relevant comparison between three-frame and four-frame stimuli ($p = 0.002$).

A pairwise comparison between different frame rates for each number of frames revealed statistical reliability at each frame rate for the same number of frames. As expected, the difference between 24 fps and 30 fps for one- and two-frame stimuli was not statistically relevant ($p > 0.9$). The most insightful results in this analysis were the comparisons between 24 fps or 30 fps and 60 fps for three-frame stimuli ($p < 0.001$). This was consistent with the possibility that three-frame stimuli could be considered subliminal at 60 fps, but not at 24 or 30 fps as their duration was less than 62 ms (Armstrong and Dienes, 2013; Cheesman and Merikle, 1984).

The location of the potential subliminal stimuli (in a cut between shots or within the shot) also proved important in this experiment ($t_{824} = 6.930$, $p < 0.001$, SE (0.257) = 0.037, 95% CI [0.184, 0.33]). Specifically, stimuli within the shot (GLMM estimated: $M = 0.498$, SD = 0.025, 95% CI [0.448, 0.547]) were more likely to be identified than stimuli between shots (GLMM estimated: $M = 0.241$, SD = 0.029, 95% CI [0.187, 0.301]).

4. Experiment 2: Viewing with Identification Task

4.1. Methods

The second experiment used Smith and Henderson's (2008) research on the detection of editing cuts in film excerpts as a methodological reference. In this study, participants were asked to press a button every time they detected a shot change involving a cut. The same active edit detection task strategy was also applied by Drew and Soto-Faraco (2024). Unlike these studies, in the present research not only was a detection task proposed, but participants also had to differentiate the target stimulus from three other distractors, converting the experiment into an identification task following a direct objective criterion.

Experiment 2 was performed by each participant individually on a computer. The screen was an Iiyama ProLite B2283HS (22 inches diagonally) with a refresh rate of 50–60 Hz. The distance between the participant and the screen was 70 cm. The procedure consisted of presenting participants with a specific image and asking them to click on the mouse (either left-clicking or right-clicking) every time that image appeared on screen. Once they had been shown the image to identify, participants watched a single video containing multiple potentially subliminal stimuli based on four different images (see Fig. 3) and were required to mark the identification of only one of those four possible images by clicking the mouse. Unlike Experiment 1, participants needed to react immediately to the stimulus so that there could be no cases of unconsolidated memory.

The film excerpt shown to participants in this experiment was taken from *All the Money in the World* (Ridley Scott, 2017) or from *I, Tonya* (Craig Gillespie, 2017). The excerpt taken from *All the Money in the World* had a duration of 7′01″ and contained 192 potentially subliminal stimuli (48 targets and 144 distractors). The excerpt from *I, Tonya* had a duration of 6′23″ and contained 176 potentially subliminal stimuli (44 targets and 132 distractors). Each potentially subliminal stimulus comprised one, two, three, or four frames, presented in random order in terms of both content and duration. However, in each film clip there was the same number of stimuli for each type of image and duration. The time distance between the inserted stimuli ranged from 2 to 4 s, depending on where the editing cuts were located. Videos at 60 fps can be accessed as examples on the OSF repository (see Supplementary Material).

The excerpt taken from *All the Money in the World* contained 84 potentially subliminal stimuli located at editing cuts, and the excerpt from *I, Tonya* contained 58. Other stimuli were inserted at random positions at least 1 s away from the nearest cut. Each excerpt was viewed by the same number of participants at each frame rate. The first image that participants were shown was the one they needed to identify whilst viewing the excerpt and the written instructions for the task. When participants were ready to start, they would click on the mouse; this would set off a time counter and a click counter (both hidden from participants), and the excerpt would begin to play in full-screen mode. The system for viewing and recording participant data was programmed in Python v.3.8.10 (Python Software Foundation, 2021) using the real-time computer vision library OpenCV v.4.6.0.66 (OpenCV team, 2022).

Because many of the stimuli were placed at editing cuts in the film excerpts, it was easy to check the consistency of participants' clicks to confirm that the time counter was synchronised to the video and thus eliminate the possibility of errors in the record. The 2- to 4-s interval separating the potentially subliminal stimuli was found to be sufficient, as no errors due to possible delays in the identification of stimuli were detected. To detect any possible delays in participants' responses, the button press time allowed each participant's target image to be compared with the last stimulus that had appeared and the stimulus preceding this. Because the participants had a specific target image, it was easy to compare whether the button press time was within the 2- to 4-s interval after the target stimulus appeared or whether it occurred sometime later after a nontarget stimulus. In no case did the participants' action occur after the 2- to 4-s interval estimated for it to be recorded as a correct response.

After viewing the excerpt, participants were given a survey (accessible for consultation via the OSF repository — see Supplementary Material) to complete containing six questions about the video's narrative content. The purpose of the survey was to mentally train the participants not to focus exclusively on the appearance of potentially subliminal stimuli, and also to pay attention to the story they were watching. This survey also made it possible to filter out participants who had not paid attention to the narrative because their responses would have had a relevantly higher number of errors than the control group. Control group participants viewed both film excerpts (*All the Money in the World* and *I, Tonya*) containing the potentially subliminal stimuli, but without having to perform an identification task. These participants only had to respond to the survey regarding the narrative content of each excerpt. These responses would be used as a reference for correct answers to determine whether any participants' results should be discarded due to a lack of attention being paid to the story narrated in the film clip. Participants were excluded unless they achieved a survey score (one point per correct answer) above the integer value of the average control group score minus the standard deviation.

Before beginning the experiment, participants completed a short pre-test to help familiarise themselves with the process. The film excerpt for this pre-test was taken from the film *The Wasteland* (*El páramo*, David Casademunt, 2021). This excerpt was 1′14″ long and contained 24 potentially subliminal stimuli, including all four images shown in Fig. 3 and a different image taken from *Sunshine* (Danny Boyle, 2007). In all cases, the image that participants were asked to identify was the one taken from *Sunshine*, which meant that no participant was required to identify the same image in both the pre-test and the experiment proper.

This pre-test viewing was considered beneficial to participants because it helped them feel more comfortable with the process. After the pre-test video, participants were asked to complete a questionnaire containing six questions about the narrative content of the clip. In this way, the presence of a survey was established in preparation for the experiment, so that in the subsequent viewing, participants would not focus their attention solely on solving the identification task.

4.1.1. Statistical Analysis

Participants' responses for each stimulus were classified as identified or unidentified and analysed by means of a GLM with a binomial link function (binary probit). The predictors defined were (i) the specific image of the stimulus, (ii) whether the stimulus was inserted within a shot or between shots, (iii) the interaction between the number of frames and frame rate (two-way interaction), and (iv) the film excerpt. Although GLM cannot define random effects, it was possible to analyse whether the film excerpt (*All the Money in the World* and *I, Tonya*) had any effect on the dependent variable (iv). Model fits were compared with an intercept-only model. To evaluate the relevance of the predictors, a Wald test was applied. To compare the different predictors, a pairwise comparison with a sequentially step-down rejective Šidák procedure was performed.

For Experiment 2, a goodness-of-fit with linear and logarithmic regression (Barrett, 2000; González-Manteiga and Crujeiras, 2013) was also conducted. This is a common methodology used to detect thresholds by fitting to a sigmoidal curve (Kingdom and Prins, 2010); however, the data collected in Experiment 2 only had samples for four temporal options, making it impossible to perform a sigmoidal adjustment. In an experimental situation using a tachistoscope, it is possible to precisely regulate the duration of the stimuli, allowing for more precise adjustments and to start from very short exposure times (Beauny *et al.*, 2020). In conducting this research, which was oriented to the audiovisual medium, the usual resources were used for its exhibition, which assumes a minimum stimulus time, as well as temporal increment multiples of this minimum. The inability to use stimuli with shorter durations or to increase their durations more precisely limited the ability to locate thresholds through a sigmoidal adjustment. Due to these inherent limitations, stimuli whose number of identifications was close to 0 were considered potentially subliminal, stimuli that stabilised the distribution of their identifications due to majority detection were considered supraliminal, and all stimuli whose number of identifications appeared in the transition between both states were considered together with other statistical approaches.

Therefore, the designed methodology sought to locate the threshold through a fit to a logarithmic function. The behaviour of a logarithmic function in this context can be interpreted as a rapid initial decrease in the number of unidentified stimuli, followed by a stabilisation in the distribution of the results, moving closer to 100% of the stimuli identified. To analyse the fit, a corrected goodness-of-fit measure was calculated (adjusted R^2).

Unlike Experiment 1, this experimental design involved a conscious identification task in which the participant focussed their attention on perceiving potentially subliminal stimuli that appeared whilst watching the video. This condition resulted in a much higher number of identifications compared with normal viewing conditions, where the participant does not focus on the location of such stimuli. This situation was similar to that in the experiments that served as references for this experimental design (Drew and Soto-Faraco, 2024; Smith and Henderson, 2008). In those experiments, which were based on detecting shot changes by cuts, the number of detected cuts was much higher than during normal film viewing. If the number of detections is the same during normal viewing, it would be impossible for the spectator to enjoy the cinematic experience of watching a film. Therefore, comparing the identification level exhibited by participants with a 0% identification level was not useful in determining the effectiveness of a stimulus in being subliminal in normal film-viewing conditions. Nevertheless, it is useful to know the probability of effectiveness in conditions where the viewer expects this resource to be used.

Thus, as in Experiment 1, a comparative adjustment to 0% of the identification results obtained was applied, as well as the likelihood distribution obtained by posterior distribution characterisation for a binomial inference based on an initial belief that identification success is 0 for each frame rate and number of frames. In this way, based on an initial belief, the probability of the event was adjusted according to the samples recorded using a Bayesian strategy. Nevertheless, it is important to take into account the limitations inherent in this part of the analysis.

4.2. Analysis of Results

Comparison of the questionnaires completed by the experimental group and the control group revealed no statistically reliable differences (for *All the Money in the World*: $t_{31} = 0.187$, $p = 0.853$ and for *I, Tonya*: $t_{31} = -0.1$, $p = 0.921$). The exclusion criteria defined by the control group results (*All the Money in the World*: $M = 4.45$, SD $= 1.184$, then accepted [3, 6]; *I, Tonya*: $M = 5.36$, SD $= 0.727$, then accepted [4, 6]) did not exclude any of the participants.

Based on the relationship between successes and mistakes for each click made by participants, the average number of erroneous clicks was 2.53% with a standard deviation of ±2.1. From these results, it was deduced that between 0.43% and 4.63% of the correct answers could have been made by chance. The proportion of correct answers was 97.47% (CI = 94.48−100%), so the results obtained from the identifications made by participants were deemed sufficiently reliable. The complete list of successes and mistakes for each click made by the participants can be accessed in the OSF repository (see Supplementary Material).

In absolute terms, without solely analysing the number of correct or incorrect clicks, it was observed that for 24 and 30 fps, the highest number of unidentified target stimuli (17.68% in both cases) and errors (24 = 3.74%; 30 = 2.83%) occurred for one frame, whilst at 60 fps, the highest number errors occurred for two- (errors = 5.88%; unidentified = 17.17%) and three-frame (errors = 3.67%; unidentified = 10.1%) stimuli. These results were consistent with stimuli that exhibited a lower probability of being identified. In this sense, it is notable that for one-frame stimuli at 60 fps, both the number of identifications (unidentified = 27.02%) and errors (2.31%) decreased.

By summing the unidentified stimuli for each number of frames, it was possible to determine the number of times that one-, two-, three- and four-frame stimuli at 24 fps, 30 fps, and 60 fps were not identified, as displayed in Fig. 5.

The results for unidentified stimuli at 24 fps (Fig. 5) revealed a remarkable difference between the number of unidentified stimuli of only one frame (70/17.68%) and the number of unidentified stimuli of two frames or more (16/4.04% for two-frame stimuli, 9/2.27% for three-frame stimuli, and 5/1.26% for four-frame stimuli). The distribution of the results indicated a logarithmic regression of Adjusted $R^2 = 0.907$ ($F_{2,1} = 30.296$, $p = 0.031$), with a sharp decline from one- to two-frame stimuli, and then a gradual decrease between two-, three-, and four-frame stimuli. The linear regression fit to the distribution of only two-, three-, and four-frame stimuli was Adjusted $R^2 = 0.951$ ($F_{1,1} = 40.141$, $p = 0.1$) but if the results for one-frame stimuli are added, the linear regression fit decreases to Adjusted $R^2 = 0.608$ ($F_{1,2} = 5.65$, $p = 0.141$).

Like the results for 24 fps, film excerpts with a frame rate of 30 fps (Fig. 5) displayed a high number of unidentified one-frame stimuli (70/17.68%). The distribution of results for 30 fps reflected a good logarithmic regression fit (Adjusted $R^2 = 0.680$, $F_{2,1} = 7.374$, $p = 0.113$), albeit lower than the fit for 24 fps. For unidentified two-, three-, and four-frame stimuli (21/5.3% for two-frame stimuli, 14/3.54% for three-frame stimuli, and 14/3.54% for four-frame stimuli), the linear regression fit was Adjusted $R^2 = 0.5$ ($F_{1,1} = 3$, $p = 0.33$). Once again, the linear regression fit was lower than it was for 24 fps. Moreover, at this frame rate, the difference in the linear regression when adding one-frame stimuli was smaller (Adjusted $R^2 = 0.547$, $F_{1,2} = 4.621$, $p = 0.165$) than the difference found for 24 fps.

In contrast to the distribution of unidentified stimuli at 24 fps and 30 fps (Fig. 5), the total number of unidentified one-frame stimuli at 60 fps (107/27.02%) did not differ dramatically from that of the longer stimuli (68/17.17% for two-frame stimuli, 40/10.1% for three-frame stimuli, and

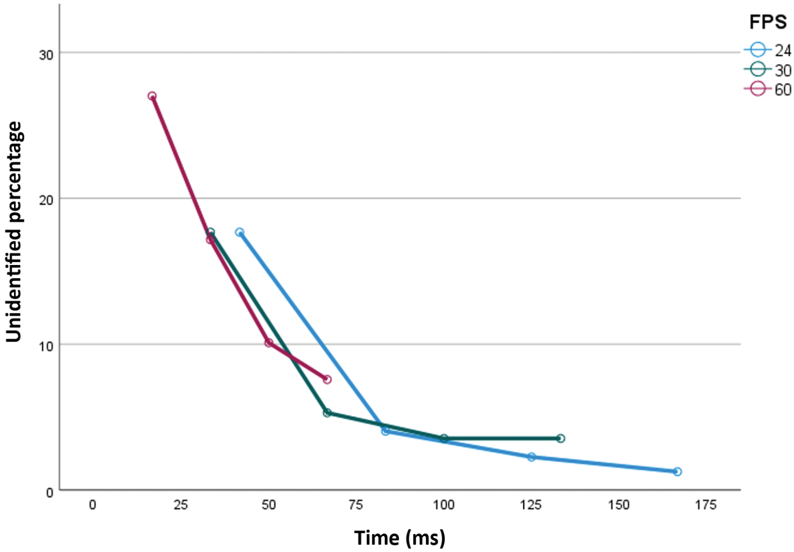

Figure 5. Time distribution of the percentages of undetected stimuli in Experiment 2 at frame rates of 24 frames per second (fps), 30 fps, and 60 fps. Data aggregated across participants.

30/7.58% four-frame stimuli). The distribution of results for 60 fps yielded a linear regression fit of Adjusted $R^2 = 0.91$ ($F_{1,2} = 31.466$, $p = 0.03$), whilst the equivalent for 24 fps was 0.608, and for 30 fps it was 0.547. The distribution of the results fitting to logarithmic regression from one- to four-frame stimuli was Adjusted $R^2 = 0.987$ ($F_{1,2} = 157.531$, $p = 0.006$) and for those fitting to linear regression from two- to four-frame stimuli, it was Adjusted $R^2 = 0.930$ ($F_{1,1} = 13.37$, $p = 0.17$).

The results obtained for 24 fps, therefore, indicated a clear behavioural difference between the one-frame stimuli analysed and the other stimuli. This marked difference between unidentified stimuli suggests that for a stimulus to have a greater chance of exerting a subliminal effect at 24 fps, it should be limited to a single frame. The results obtained for 30 fps reveal a similar behavioural difference between one-frame stimuli and the other stimuli. However, the behaviour identified for two-frame stimuli was less homogeneous with that of three- and four-frame stimuli than it was in the results observed at a frame rate of 24 fps. Concomitantly, the number of unidentified two-frame stimuli at 60 fps (68) was similar to the number of unidentified one-frame stimuli at 24 fps (70) and 30 fps (70).

When a z test was performed to assess the frequency of identifications with regard to 0% success, the frequencies were statistically different for every number of frames and frame rates (see Supplementary Material). To analyse the likelihood that the stimulus would not be identified, posterior distribution characterisation for binomial inference was applied. The posterior mean for all numbers of frames across all frequency rates was always less than 50%, indicating that stimuli were more likely to be identified than not (see Supplementary Material). Specifically, the posterior mean for one-frame stimuli was 0.74 for 24 fps, 0.74 for 30 fps and 0.61 for 60 fps. For two-frame stimuli, the posterior mean was 0.94 for 24 fps, 0.92 for 30 fps, and 0.75 for 60 fps. These results clearly indicate that if viewers are attentive to the appearance of subliminal stimuli in a film, these will be identified in most cases.

4.2.1. Generalised Linear Model

The statistical reliability of the differences identified in participant perceptions was evaluated by means of a GLM. In total, 100% of the samples were included in the GLM analysis (N = 3312, 828 stimuli for each number of frames stimuli, 1,104 for each frame rate, 828 for each different stimulus, 1,728 stimuli in the *All the Money in the World* excerpt, and 1,584 stimuli in the *I, Tonya* excerpt). According to the omnibus test, the dependent value that represents the stimulus identification (0, unidentified; 1, identified) yielded a strong fit between the model and the intercept-only model [χ^2_{16} ($N = 3312$) = 403.721, $p < 0.001$].

The effects identified as statistically relevant were the two-way interaction number of frames*frame rate [χ^2_{11} ($N = 3312$) = 296.398, $p < 0.001$] and the specific image of the stimuli [χ^2_3 ($N = 3312$) = 57.382, $p < 0.001$], but these were not statistically relevant if the stimuli were between shots or at a cut [χ^2_1 ($N = 3312$) = 0.01, $p = 0.919$)] or when comparing the different film excerpts [χ^2_1 ($N = 3312$) = 2.695, $p = 0.101$]. Pairwise comparisons for the number of frames for each frame rate, for different frame rates for each number of frames, and for the specific image of the stimuli and for stimuli of similar duration [33.3 ms, 41.7 ms] are available for consultation in the OSF repository (see Supplementary Material).

A pairwise comparison between different numbers of frames for each frame rate yielded a statistically relevant difference ($p < 0.001$) for 24 fps and 30 fps between one-frame stimuli and those of any other number of frames, but not in other pairwise comparisons ($p > 0.05$). These results suggest that one-frame stimuli exerted a markedly different effect from two-, three-, and four-frame stimuli at 24 and 30 fps. In the case of 60 fps, there was a clear differentiation ($p < 0.001$) between one-frame stimuli and three- or four-frame stimuli, and between two- and four-frame stimuli. For this frame rate, there was also a statistically reliable difference ($p = 0.009$) between one- and two-frame stimuli, whilst the pairwise comparison between two- and three-frame stimuli (p = 0.052) was close to being statistically reliable ($p < 0.05$). The lowest mean differentiation was between three- and four-frame stimuli ($p = 0.947$). The results of this experiment revealed a clear difference at 60 fps between one-frame stimuli and those of two or more frames, and also an important difference between two-frame stimuli and four-frame stimuli.

A pairwise comparison between different frame rates for each number of frames revealed a statistically relevant distinction between different frame rates for stimuli of the same number of frames. The most statistically relevant differences were found between 24 or 30 fps and 60 fps, specifically for one-, two- and three-frame stimuli ($p \leq 0.005$). As expected, there were no clear differences in the pairwise comparisons between 24 fps and 30 fps, especially for one-, two- and three-frame stimuli ($p > 0.9$). It is also useful to note that stimuli of similar duration [33.3 ms, 41.7 ms] yielded similar values ($p = 0.999$).

A pairwise comparison between images used as potential subliminal stimuli revealed the effect of the different images used. In this experiment, statistically relevant differences ($p < 0.001$) were found between the still frames extracted from *Se7en* (face over white background) and *The Thin Red Line* (textured colour) and those extracted from *In the Earth* (fragment of a flower) and *First Blood* (geometric pattern). Specifically, identification of the stimuli from *Se7en* (GLM estimated: $M = 0.14$, SD = 0.013, 95% Wald CI [0.11, 0.16]) and *The Thin Red Line* (GLM estimated: $M = 0.16$, SD = 0.013, 95% Wald CI [0.13, 0.19]) was found to be more likely than identification of the stimuli from *In the Earth* (GLM estimated: $M = 0.08$, SD = 0.01, 95% Wald CI [0.06, 0.1]) and *First Blood* (GLM estimated: $M = 0.06$, SD = 0.008, 95% Wald CI [0.04, 0.08]).

5. Discussion

Although there has been no quantitative research in the field of film studies on the duration of subliminal stimuli, there is an abundance of literature on this question in experimental psychology. Based on previous studies (Armstrong and Dienes, 2013; Cheesman and Merikle, 1984; Phillips *et al.*, 2004), it can be estimated that a subliminal stimulus should be at least around 20 ms in order to exceed the objective threshold, and no more than 80 ms so as not to exceed quite probably the subjective threshold which would make it supraliminal. This estimate is a relative approximation, as it is dependent on the images appearing before and after the stimulus, as well as the formal nature of the stimulus itself. Furthermore, these durations must be adapted to the specific possibilities allowed by cinematographic reproduction, making it impossible to achieve durations that are not multiples of the duration of a frame depending on the reproduction frequency. Only in this way can temporal thresholds be applicable in the film industry. In this sense, the time threshold of 80 ms is also coherent with experiments focusing on shot change detection, as all the results reported in these experiments are above this duration (Shimamura *et al.*, 2015; Smith *et al.*, 2012).

According to these temporal estimates, one-frame stimuli at 24 fps fit clearly within the estimated range, whereas a two-frame stimulus at the same frame rate exceeds the upper limit by 3.33 ms. In the case of a frame rate of 30 fps, a single frame fits perfectly within the estimated time range; however, two frames are close to the subjective threshold (falling short by only 13.33 ms), as are four frames at 60 fps. Given that the 80 ms threshold is a relative approximation, it is difficult to categorise a two-frame stimulus at either 24 fps or 30 fps and a four-frame stimulus at 60 fps as either subliminal or supraliminal. As reflected in the results of Experiment 1 and Experiment 2, whether stimuli of these durations are unidentifiable by viewers will depend on various factors such as the attention paid by the spectator. Indeed, previous research has revealed that the repetition of stimuli and participants' knowledge about the experiment can affect their attention and consequently the results (Grill-Spector *et al.*, 2006; VanRullen *et al.*, 2011).

The methodology designed for this study, based on two different but complementary experiments following a direct objective criterion, facilitates the definition of thresholds of duration (in terms of number of frames) for stimuli that could be considered subliminal in films. The research mentioned as references for the methodological design for Experiment 2 (Drew and Soto-Faraco, 2024; Smith and Henderson, 2008) are procedures usually linked to the detection of stimuli (absence/presence). The present research, by contrast, required more than mere detection, as it also involved identification which obviously implies conscious processes with the intention of differentiating whether the stimuli can affect the story entities, the event models or produce subliminal effects. Although the design of Experiment 1 included a temporal delay between the participant's exposure to the stimulus and the questionnaire, the differentiation between a subliminal stimulus and a supraliminal stimulus that has not been consolidated enough to be maintained over time may be ambiguous. What this setup confirmed, however, was that identification reflected a supraliminal condition, acquiring the potential capacity to influence the story entities or the event models. Experiment 2, however, did not present a separation between the stimulus and the participant's report indicating its identification; hence, the possible ambiguity of Experiment 1 did not appear. Consequently, the most reliable results to be considered subliminal were those related to durations that appeared as unidentified in both experiments, being ambiguous only when they were unidentified in Experiment 1.

The main advantage of Experiment 1 is that its design more closely resembled the film-viewing experience than Experiment 2. Conversely, Experiment 2 allowed the inclusion of a larger number of repetitions of the potentially subliminal stimulus for each participant. Furthermore, it involved a strong manipulation of the original material, thereby distancing the film excerpt from its original design. A large number of potentially subliminal stimuli were inserted without a narrative design, which is contrary to cinematographic narrative techniques. In traditional cinematographic narrative, all applied resources are typically oriented towards a narrative objective. An inevitable disadvantage of both experiments was the way in which they distorted the spectatorial experience. In Experiment 1, participants reached a point where they recognised the objective of the study, whereas in Experiment 2, the typical attentional processes of the cinematographic spectator were altered by the nature of the identification task assigned to them.

In Experiment 1, which involved an identification task (but not with a forced choice) of potentially subliminal stimuli without participants having prior knowledge of the study objective, it was not possible to achieve a statistically relevant adjustment of the results to a 0% identification. In previous research analysing the effect of subliminal stimuli on participants, it is customary to calculate the objective and subjective thresholds for each participant and adjust the durations of stimuli to each individual's cognitive characteristics. This ensures that all participants are exposed to subliminal stimuli, achieving a potential adjustment to 0% of identifications (Hinze *et al.*, 2021; Pessiglione *et al.*, 2007). Consequently, in some experiments, these adjustments can fail because the estimated thresholds for each participant vary from trial to trial (Miller, 1991). Regarding the variability in each participant's perception, some studies have been able to estimate with relatively high accuracy [area under the curve (AUC) = 0.70] whether a stimulus will be identified by a participant. This estimation is based on lateralised electroencephalographic activity before the stimulus, the hemifield where the stimulus was presented, and the accuracy of the previous trial's discrimination response (Railo *et al.*, 2021).

However, beyond trial-to-trial variations in each participant, the nature of the cinematographic medium does not allow this adaptation for each participant when viewing, as films are shown with the same frequency of reproduction for all spectators. The only way to ensure an adjustment to 0% of identifications in an experimental system displaying stimuli with the same duration for all participants is to use stimuli with a duration close to the objective threshold. This ensures that participants' cognitive variability does not exceed the subjective threshold, potentially enabling a 0% identification rate, but does not ensure that all stimuli surpass the objective threshold for all participants. Moreover, this approach probably requires a playback rate faster than 60 fps which is uncommon in films.

Previous experiments had been conducted with stimuli of both 16 ms (Wang *et al.*, 2021) — equal to a stimulus presented at 60 fps — and 33 ms (Sim *et al.*, 2020) — equivalent to a stimulus presented at 30 fps — considering stimuli presented in both cases as subliminal. Another strategy for analysing the subliminal effect in a near-liminal condition is to select those participants for whom the stimulus acts as subliminal and discard the rest. This approach, as proposed by the Bayesian hierarchical model MAC (Morey *et al.*, 2008; Rouder *et al.*, 2007), involves discarding the possibility of a 0% identification adjustment in the results prior to rejecting some participants' samples.

In the present study, the focus was not on evaluating the repercussions of the subliminal stimulus, but on the ability of the cinematographic medium to generate subliminal stimuli under its most usual reproduction conditions (24, 30, and 60 fps). Therefore, it was necessary to evaluate whether the stimuli presented could act mostly subliminally among the participants. Achieving a perfect adjustment to 0% of identifications was not the goal due to the nature of the medium. Therefore, calculating the likelihood distribution obtained by posterior distribution characterisation for binomial inference based on an initial belief that identification success is 0% usefully reflected the potential effectiveness of creating subliminal stimuli in films at different frame rates for different numbers of frames.

Therefore, it is crucial to emphasise that because there was no adjustment to 0% identifications in Experiment 1, it is not possible to define subliminal stimuli in films in an absolute form for all participants. When defining whether a stimulus can be considered subliminal in films, it is important to consider that it will mostly have this effect on the viewers, but that it is not as effective among all spectators. The possibility of supraliminal perception is especially increased if viewers are aware of the potential appearance of a subliminal stimulus and focus their attention on its identification, as seen in Experiment 2.

Furthermore, it is necessary to take into consideration the criterion problems in participants' identifications, both in questioners and in the task whilst watching the film excerpt (Michel, 2023a,b). When participants are not clear about whether they have perceived an image, they must decide whether or not to report it when requested. This implies that the participants themselves must establish a personal threshold related to the certainty they have regarding their own perception of the stimulus, defining from which level of consciousness they report an image and from which point they do not. This leads to experiments where the number of images perceived is rewarded and participants tend to select more images, maximising the correct answers (liberal response criterion), whereas if errors are punished, participants tend to report fewer images, minimising erroneous identifications (conservative response criterion). These variations are minimised in detection or identification tasks that require rapid responses as in Experiment 2, and maximised in situations where responses involve reflection on the part of participants (Michel, 2023a) as in Experiment 1.

Having considered these observations, in film content played at frame rates of 24 fps and 30 fps, the stimuli that are more likely to be considered subliminal according to the results of Experiment 1 and Experiment 2 are those contained in a single frame, given the statistically relevant difference between three- and four-frame stimuli, which should be considered supraliminal. The most striking results were those related to two-frame stimuli. In Experiment 2 for 24 fps and 30 fps where participants were clearly focussed on identification from the outset, and in Experiment 1 for 30 fps, from the point when they were likely to consciously modify their attentional goals to focus on identification after completing the first survey (2-frame-B), two frames could not be considered a suitable duration for a subliminal stimulus. However, in the first viewing of Experiment 1 (2-frame-A), when participants had not yet completed the first survey, the results revealed a higher percentage of unidentified stimuli, suggesting that a duration of two frames could be considered subliminal, especially for 30 fps. This conclusion is supported by the GLMM and GLM analysis in experiments 1 and 2. Experiment 2 revealed a statistically relevant difference between one- and two-frame stimuli, whilst for Experiment 1 the difference was less clear.

Moreover, there is the possibility that the two-frame stimuli at 24 and 30 fps were perceived but not consolidated in memory, thus discarding them as possible subliminal stimuli. This possibility would be consistent with the results indicating an increase in the number of identifications between 2-frame-A and 2-frame-B at 30 fps, as repeated exposure of the stimuli increased the potentiality of their consolidation in memory. Indeed, there are experiments based on RSVP in which repetition of the stimuli shown increases the possibility of their consolidation in memory (Martini and Maljkovic, 2009; Thunell and Thorpe, 2019).

Based on the results of the viewings at 60 fps in Experiment 1 and Experiment 2, one- and two-frame stimuli may suitably be classified as not supraliminal. In Experiment 2, there was a high number of unidentified three-frame stimuli, and there was no logarithmic fit that would allow the clear definition of a possible threshold. However, spectator perception in Experiment 1 was not as low as might have been expected. Moreover, for 60 fps in this experiment, it is believed that participants may have focussed their attention on identifying the stimulus for the three- and four-frame stimuli because of the repetition of tests and surveys. The GLMM and GLM analyses were not as conclusive for three-frame stimuli. However, the difference between three-frame stimuli at 24 or 30 fps and three-frame stimuli at 60 fps is relevant because at 24 and 30 fps this number of frames can be considered supraliminal. There was also a clear difference between one-frame stimuli and two- and three-frame stimuli at 60 fps.

At 60 fps, depending on the time estimate taken as a benchmark (Armstrong and Dienes, 2013; Cheesman and Merikle, 1984; Phillips *et al.*, 2004), a single frame would fall beneath the objective threshold and would therefore probably not be considered subliminal. In Experiment 2, there was a small number of identifications, but there was also a lower number of clicks on nontarget images than for two- and three-frame stimuli. This situation could explain the statistically relevant differences between one-frame stimuli and two- or three-frame stimuli. However, two-, three-, and four-frame stimuli all fit within the estimated range. Once again, the results obtained for two- and three-frame stimuli appear to fit this estimate, but for four-frame stimuli the same situation may occur as for two-frame stimuli at 30 fps. This suggests that identification could be dependent on the development of the experiment itself (VanRullen *et al.*, 2011), or possibly that the stimuli are not subliminal and that repetition improves their memory consolidation (Martini and Maljkovic, 2009).

Another important finding of this research relates to the possible effect of the nature of the image used as a subliminal stimulus, and whether it was located within a shot or at a cut between shots. This possibility is particularly important because it suggests that the nature of the stimulus or the technical context in which it is embedded might determine its identification by the spectator, potentially influencing its effectiveness and intensity of impact. These results align with literature that analyses shot changes in film editing, as seen in academic research (Smith and Henderson, 2008; Smith *et al.*, 2012) and technical manuals (Marimón, 2015; Thompson and Bowen, 2009), as cuts are usually designed to be unnoticed by the spectator. In Experiment 1, where participants' attention was guided less by the experimental premises, the location of the stimuli in a cut made a statistically relevant difference, but this was not the case in Experiment 2 where participants had been focussed from the outset on detecting and identifying the stimuli. Conversely, the kind of image used as stimuli made a statistically relevant difference to the probability of their identification in Experiment 2, but not in Experiment 1. These results suggest that the location of the stimuli, either within the shot or at a cut between shots, and the nature of the image used as a stimulus could be important for defining the subliminal threshold, although further, more specific experiments are needed to explore this question in more detail.

The results presented are relevant for creating narrative absorption in films (Kuijpers *et al.*, 2021; Tan *et al.*, 2017), promoting an aesthetic illusion in the spectator (Wolf, 2004). This mechanism, which is triggered in the viewer, causing them to reduce their level of self-consciousness and focus attentional resources on narrative absorption, is one of the essential points the film editor frequently addresses, ensuring that the technical aspects do not disrupt this form of vicarious film experience. Such is the importance of this professional practice that Bazin (1958/1985) applied the term *forbidden montage* to all those editing techniques that made it difficult to focus on the narrative, giving rise to technical awareness of the device and, ultimately, the appearance of self-consciousness as a person watching a film. In this technical-discursive sense, the inclusion of a subliminal image means including an element foreign to the photogrammatic chain. This implies that its conscious perception does not favour the fluidity of the narrative, but instead abruptly terminates it. As a consequence, this awareness of the visual impact could break the focalisation of the spectator on the narration and redirect attention to the cinematographic technique, that is, to the cinematographic artefact that is a film.

Therefore, this research has special relevance for film editors. It is crucial to use subliminal stimuli precisely, as their misuse can result in an unwanted effect on the viewer. These subliminal stimuli have an effect on the characteristics of the artefact, whereas the supraliminal stimuli have an effect on the story entities or event models. Having precise knowledge that a stimulus varies between subliminal and supraliminal in the range of one to three frames is especially valuable for film editors because it will enable them to safely predict whether the stimulus will remain subliminal and not affect the characteristics of the artefact, or whether it could potentially be included in the story -entities or event models.

According to the results obtained, in the case of 30 fps and 24 fps, there are several relevant ontological consequences of identifying that the stimuli most likely to be subliminal are the isolated frames. In this regard, the word "shot" constitutes an etymological problem for the development of film theory, as it is a term used both in cinematography and in still photography. Etymologically, it has a closer association with the act of capturing an image in a static frame than with the result of a moving image. Given this, the proposal here is to use the French term *plan* instead, which has a closer etymological link to two-dimensional moving images than the act of photography.

The *plan* contains both time and space (Burch, 1969), rendering it essential in the spatio-temporal articulation of a film's virtuality (Deleuze, 1984/1986; Deleuze, 1985/1996). As it develops it advances the narrative (Marimón, 2015), and it therefore must necessarily be perceived as supraliminal. In a cinematic context, a *plan* is operated on by the others that surround it, just as it in turn modifies those other *plans* (Kuleshov, 1934/1994; Oudart, 2005). These features of the *plan* make it the technical unit that underpins the context of reference for a series of frames.

On the other hand, the subliminal frame in isolation contains no time as it does not involve a succession. For this reason, a frame in isolation cannot construct time or space in the virtuality of the film. Moreover, as it is not developed but is designed to go unperceived, it cannot advance the film narrative, because its dimension as a signifier is not even recognised.

In the context of a film, although it changes the way the *plans* that follow it are perceived, the subliminal frame allows no inference about previous *plans* in its meaning. Attending these characteristics, the subliminal stimulus created by an isolated frame cannot be described as a *plan*, but instead requires a specific label of its own. Its status is that of an extraneous element inserted into a series of frames with the aim of altering the cognition of the spectator, but without acting as an element integrated into the film's narrative.

6. Conclusions

Based on the experiments described in this article, the first noteworthy conclusion is that, based on the common playback frequencies in cinema such as 24, 30, and 60 fps, there is no likelihood of a stimulus that can be considered subliminal for absolutely all viewers in all situations. Therefore, the definition of subliminal stimuli in films should be those that are more likely to be perceived by spectators in a subliminal way rather than in a supraliminal way. Therefore, according to the results of Experiment 1, one-frame stimuli for 24, 30, and 60 fps and two-frame stimuli for 60 fps are considered effective. Additionally, two-frame stimuli for 24 and 30 fps and three-frame stimuli for 60 fps are considered moderately effective. It should be noted that the results regarding the perception of the four-frame stimuli at 60 fps may strongly depend on being included in the fourth fragment shown to the viewers whose attention was probably focussed on its identification, distorting the results obtained.

Given this consideration, the stimuli that have a higher probability of being subliminal are the isolated frames at 24 fps or 30 fps and two- and three-frame stimuli at 60 fps. For two frames at 24 fps and 30 fps, and for one and four frames at 60 fps, the results obtained were deemed inconclusive. Thus, it is suggested here that the identification of two-frame stimuli at 24 fps or 30 fps and four-frame stimuli at 60 fps may depend on variable conditions such as the attention of the spectator. Their identification may also be affected by other formal elements such as the visual content of the stimulus and whether it is inserted within a shot or at a cut between shots. Conversely, a one-frame stimulus at 60 fps is unlikely to surpass the objective threshold for all spectators, and thus would not even trigger the neural processes necessary to be defined as subliminal in these cases.

An intriguing possibility is that the nature of the image used as a subliminal stimulus and its location at a cut or within the shot could influence its identification. Although this study points to this possibility, further research is needed to better understand this question and reach clear conclusions.

Finally, the above findings also suggest that an isolated frame shown at a frame rate of 24 fps or 30 fps may be subliminal, but cannot be included in the *plan* category. It would therefore be appropriate to classify such frames differently due to their status as extraneous elements within the film's series of frames. In this study, the term *isolated subliminal frame* is proposed to refer to this type of image, differentiating it ontologically from those shots that can be classified in the category of *plan*.

Supplementary material

Supplementary material is available online at:
https://doi.org/10.6084/m9.figshare.26779636

References

AgbangbaI, C. E., Aide, E. S., Honfo, H. and Kakai, R. G. (2024). On the use of post-hoc tests in environmental and biological sciences: A critical review, *Heliyon* **10**, e25131. https://doi.org/10.1016/j.heliyon.2024.e25131.

Armstrong, A.-M. and Dienes, Z. (2013). Subliminal understanding of negation: Unconscious control by subliminal processing of word pairs, *Consc. Cogn.* **22**, 1022–1040. https://doi.org/10.1016/j.concog.2013.06.010.

Barrett, G. B. (2000). The Coefficient of Determination: Understanding r squared and R squared, *Math. Teach.* **93**, 230–234. https://doi.org/10.5951/MT.93.3.0230.

Bazin, A. (1985). Montage interdit, in: *Qu'est-ce que le cinéma?* pp. 49–61. Éditions du Cerf, Paris, France (originally published 1958).

Beauny, A., de Heering, A., Muñoz Moldes, S., Martin, J.-R., de Beir, A. and Cleeremans, A. (2020). Unconscious categorization of sub-millisecond complex images, *PloS One*, **18**, e0236467. https://doi.org/10.1371/journal.pone.0236467.

Berkovitch, L. and Dehaene, S. (2019). Subliminal syntactic priming, *Cogn. Psychol.* **109**, 26–46. https://doi.org/10.1016/j.cogpsych.2018.12.001.

Bermeitinger, C. and Wentura, D. (2016). Moving single dots as primes for static arrow targets, *Exp. Psychol.* **63**, 127–139. https://doi.org/10.1027/1618-3169/a000321.

Bordwell, D. (1991). Interpretation as construction, in: *Making Meaning: Inference and Rhetoric in the Interpretation of Cinema*, pp. 1–7. Harvard University Press, Cambridge, MA, USA.

Boy, F., Husain, M. and Sumner, P. (2010). Unconscious inhibition separates two forms of cognitive control, *Proc. Natl Acad. Sci.* **107**, 11134–11139. https://doi.org/10.1073/pnas.1001925107.

Burch, N. (1969). *Praxis du Cinéma*. Gallimard, Paris, France.

Cheesman, J. and Merikle, P. (1984). Priming with and without awareness, *Percept. Psychophys.* **36**, 387–395. https://doi.org/10.3758/BF03202793.

Coltheart, V. (1999). Comparing short-term memory and memory for rapidly presented visual stimuli, *Int. J. Psychol.* **34**, 293–300. https://doi.org/10.1080/002075999399594.

Deleuze, G. (1986). *Cinema 1: The Movement-lmage*. University of Minnesota Press, Minneapolis, MN, USA. (Original work published 1984).

Deleuze, G. (1996). *La Imagen-Tiempo: Estudios Sobre Cine 2*. Ediciones Paidós, Barcelona, Spain (originally published 1985).

Drew, A. and Soto-Faraco, S. (2024). Perceptual oddities: assessing the relationship between film editing and prediction processes, *Philos. Trans. R. Soc. B Biol. Sci.* **379**, 20220426. https://doi.org/10.1098/rstb.2022.0426.

Eisenstein, S. (1977). The cinematographic principle and the ideogram, in: *Film Form: Essays in Film Theory*, pp. 28–45. Harcourt Brace & Co. New York, NY, USA.

Fahrenfort, J. J., Scholte, H. S. and Lamme, V. A. F. (2007). Masking disrupts reentrant processing in human visual cortex, *J. Cogn. Neurosci.* **19**, 1488–1497. https://doi.org/10.1162/jocn.2007.19.9.1488.

Friday, K. (2003). "A generation of men without history": Fight club, masculinity, and the historical symptom, *Postmod. Cult.* **13**, 2003.0016. https://doi.org/10.1353/pmc.2003.0016.

González-Manteiga, W. and Crujeiras, R. M. (2013). An updated review of Goodness-of-Fit tests for regression models, *Test* **22**, 361–411. https://doi.org/10.1007/s11749-013-0327-5.

Grootswagers, T., Robinson, A. K., and Carlson, T. A. (2019). The representational dynamics of visual objects in rapid serial visual processing streams, *Neuroimage* **188**, 668–679. https://doi.org/10.1016/j.neuroimage.2018.12.046.

Grill-Spector, K., Henson, R. and Martin, A. (2006). Repetition and the brain: neural models of stimulus-specific effects, *Trends Cogn. Sci.* **10**, 14–23. https://doi.org/10.1016/j.tics.2005.11.006.

Hinze, V. K., Uslu, O., Antono, J. E., Wilke, M., and Pooresmaeili, A. (2021). The effect of subliminal incentives on goal-directed eye movements, *J. Neurophysiol.* **126**, 2014–2026. https://doi.org/10.1152/jn.00414.2021.

Jaśkowski, P. and Przekoracka-Krawczyk, A. (2005). On the role of mask structure in subliminal priming, *Acta Neurobiol. Exp. (Wars.)* **65**, 409–417. https://doi.org/10.55782/ane-2005-1569.

Keysers, C. and Perrett, D. I. (2002). Visual masking and RSVP reveal neural competition, *Trends Cogn. Sci.* **6**, 120–125. https://doi.org/10.1016/S1364-6613(00)01852-0.

Kingdom, F. A. A. and Prins, N. (2010). *Psychophysics: A Practical Introduction*. Elsevier, Amsterdam, Netherlands.

Kuijpers, M. M., Douglas, S. and Bálint, K. (2021). Narrative absorption: An overview, in: *Handbook of Empirical Literary Studies*, D. Kuiken and A. M. Jacobs (Eds), pp. 279–304. Walter de Gruyter GmbH & Co KG, Berlin, Germany. https://doi.org/10.1515/9783110645958-012.

Kuleshov, L. (1994). *L'Art du Cinéma et Autres Écrits*. L'Age d'Homme, Levier, France (originally published 1934).

Lai, C., Pellicano, G. R., Ciacchella, C., Guidobaldi, L., Altavilla, D., Cecchini, M., Begotaraj, E., Aceto, P. and Luciani, M. (2020). Neurophysiological correlates of emotional face perception consciousness, *Neuropsychologia* **146**, 107554. https://doi.org/10.1016/j.neuropsychologia.2020.107554.

Leek, M. R. (2001). Adaptive procedures in psychophysical research, *Percept. Psychophys.* **63**, 1279–1292. https://doi.org/10.3758/BF03194543.

Loschky, L. C., Larson, A. M., Smith, T. J. and Magliano, J. P. (2020). The scene perception & event comprehension theory (SPECT) applied to visual narratives, *Top. Cogn. Sci.* **12**, 311–351. https://doi.org/10.1111/tops.12455.

Magliano, J. P., Miller, J. and Zwaan, R. A. (2001). Indexing space and time in film understanding, *Appl. Cogn. Psychol.* **15**, 533–545. https://doi.org/10.1002/acp.724.

Manor, R. and Geva, A. B. (2015). Convolutional neural network for multi-category rapid serial visual presentation BCI, *Front. Comput. Neurosci.* **9**, 146. https://doi.org/10.3389/fncom.2015.00146.

Marimón, J. (2015). *El Muntatge Cinematogràfic. Del Guió a la Pantalla*. Edicions de la Universitat de Barcelona, Barcelona, Spain.

Martini, P. and Maljkovic, V. (2009). Short-term memory for pictures seen once or twice, *Vision Res*. **49**, 1657–1667. https://doi.org/10.1016/j.visres.2009.04.007.

Michel, M. (2023a). The old and new criterion problems, in: *Conscious and Unconscious Mentality: Examining Their Nature, Similarities, and Differences*, J. Hvorecký, T. Marvan and M. Polák (Eds), pp. 130–154. Routledge, London, United Kingdom.

Michel, M. (2023b). How (not) to underestimate unconscious perception, *Mind Lang*. **38**, 413–430. https://doi.org/10.1111/mila.12406.

Miller, J. (1991). Threshold variability in subliminal perception experiments: Fixed threshold estimates reduce power to detect subliminal effects, *J. Exp. Psychol. Hum. Percept. Perform*. **17**, 841–851. https://doi.org/10.1037/0096-1523.17.3.841.

Milner, A. D. and Goodale, M. A. (2006). *The Visual Brain in Action*. Oxford University Press, Oxford, United Kingdom.

Monahan, J. L., Murphy, S. T. and Zajonc, R. B. (2000). Subliminal mere exposure: Specific, general, and diffuse effects, *Psychol. Sci*. **11**, 462–466. https://doi.org/10.1111/1467-9280.00289.

Morey, R. D., Rouder, J. N., and Speckman, P. L. (2008). A statistical model for discriminating between subliminal and near-liminal performance, *J. Math. Psychol*. **52**, 21–36. https://doi.org/10.1016/j.jmp.2007.09.007.

Nanay, B. (2017). Perceptual learning, the mere exposure effect and aesthetic antirealism, *Leonardo* **50**, 58–63. https://doi.org/10.1162/LEON_a_01082.

Newell, B. R. and Shanks, D. R. (2014). Unconscious influences on decision making: A critical review, *Behav. Brain Sci*. **37**, 1–19. https://doi.org/10.1017/S0140525X12003214.

Núñez, J. P. and de Vicente, F. (2004). Unconscious learning. Conditioning to subliminal visual stimuli, *Sp. J. Psychol*. **7**, 13–28. https://doi.org/10.1017/S1138741600004716.

OpenCV team (2022). *Open Source Computer Vision Library* (Version 4.6.0.66) [Software]. OpenCV team. https://github.com/opencv/opencv/wiki/ChangeLog#version460.

Oudart, J.-P. (2005). La sutura, in: *Teoría y Crítica del Cine. Avatares de Una Cinefilia*, A. De Baecque (Ed.), pp. 52–68. Ediciones Paidós, Barcelona, Spain.

Overgaard, M., Rote, J., Mouridsen, K. and Ramsøy, T. Z. (2006). Is conscious perception gradual or dichotomous? A comparison of report methodologies during a visual task, *Consc. Cogn*. **15**, 700–708. https://doi.org/10.1016/j.concog.2006.04.002.

Pan, F., Wu, X., Zhang, L. and Ou, Y. (2017). Inhibition of return is modulated by negative stimuli: evidence from subliminal perception, *Front. Psychol*. **8**, 1012. https://doi.org/10.3389/fpsyg.2017.01012.

Parkinson, J. and Haggard, P. (2014). Subliminal priming of intentional inhibition, *Cognition* **130**, 255–265. https://doi.org/10.1016/j.cognition.2013.11.005.

Pessiglione, M., Schmidt, L., Draganski, B., Kalisch, R., Lau, H., Dolan, R. J., and Frith, C. D. (2007). How the brain translates money into force: a neuroimaging study of subliminal motivation, *Science* **316**, 904–906. https://doi.org/10.1126/science.1140459.

Phillips, M. L., Williams, L. M., Heining, M., Herba, C. M., Russell, T., Andrew, C., Bullmore, E. T., Brammer, M. J., Williams, S. C. R., Morgan, M., Young, A. W. and Gray, J. A. (2004). Differential neural responses to overt and covert presentations of facial expressions of fear and disgust, *Neuroimage* **21**, 1484–1496. https://doi.org/10.1016/j.neuroimage.2003.12.013.

Potter, M. C. (2012). Conceptual short-term memory in perception and thought, *Front. Psychol*. **3**, 1–11. https://doi.org/10.3389/fpsyg.2012.00113.

Potter, M. C., Staub, A. and O'Connor, D. H. (2002). The time course of competition for attention: Attention is initially labile, *J. Exp. Psychol. Hum. Percept. Perform*. **28**, 1149–1162. https://doi.org/10.1037//0096-1523.28.5.1149.

Python Software Foundation (2021). *Python* (Version 3.8.10) [Software]. Python Software Foundation. https://docs.python.org/release/3.8.10/.

Railo, H., Piccin, R., and Lukasik, K. M. (2021). Subliminal perception is continuous with conscious vision and can be predicted from prestimulus electroencephalographic activity, *Eur. J. Neurosci*. **54**, 4985–4999. https://doi.org/10.1111/ejn.15354.

Ricker, T. J. and Hardman, K. O. (2017). The nature of short-term consolidation in visual working memory, *J. Exp. Psychol. Gen*. **146**, 1551–1573. https://doi.org/10.1037/xge0000346.

Robinson, A. K., Grootswagers, T. and Carlson, T. A. (2019). The influence of image masking on object representations during rapid serial visual presentation, *Neuroimage* **197**, 224–231. https://doi.org/10.1016/j.neuroimage.2019.04.050,.

Rouder, J. N., Morey, R. D., Speckman, P. L., and Pratte, M. S. (2007). Detecting chance: A solution to the null sensitivity problem in subliminal priming, *Psychon. Bull. Rev*. **14**, 597–605. https://doi.org/10.3758/BF03196808.

Salpeter, L. R. and Swirsky, J. I. (2011). Historical and legal implications of subliminal messaging in the multimedia: Unconscious subjects, *Nova Law Rev*. **36**, 4.

Sandberg, K., Bibby, B. M., Timmermans, B., Cleeremans, A. and Overgaard, M. (2011). Measuring consciousness: Task accuracy and awareness as sigmoid functions of stimulus duration, *Consc. Cogn*. **20**, 1659–1675. https://doi.org/10.1016/j.concog.2011.09.002.

Schlaghecken, F. and Eimer, M. (2004). Masked prime stimuli can bias "free" choices between response alternatives, *Psychon. Bull. Rev*. **11**, 463–468. https://doi.org/10.3758/BF03196596.

Shimamura, A. P., Cohn-Sheehy, B. I., Pogue, B. L. and Shimamura, T. A. (2015). How attention is driven by film edits: A multimodal experience, *Psychol. Aesthet. Creat. Arts* **9**, 417–422. https://doi.org/10.1037/aca0000025.

Šidák, Z. (1967). Rectangular confidence regions for the means of multivariate normal distributions, *J. Am. Stat. Assoc*. **62**, 626–633. https://doi.org/10.1080/01621459.1967.10482935.

Sim, E.-J., Harpaintner, M., and Kiefer, M. (2020). Is subliminal face processing modulated by attentional task sets? Evidence from masked priming effects in a gender decision task, *Open Psychol*. **2**, 76–89. https://doi.org/10.1515/psych-2020-0006.

Smith, T. J. and Henderson, J. M. (2008). Edit Blindness: The relationship between attention and global change blindness in dynamic scenes, *J. Eye Mov. Res*. **2**, 1–17. https://doi.org/10.16910/jemr.2.2.6.

Smith, T. J., Levin, D. and Cutting, J. E. (2012). A window on reality: Perceiving edited moving images, *Curr. Dir. Psychol. Sci*. **21**, 107–113. https://doi.org/10.1177/0963721412437407.

Szczepanowski, R. and Pessoa, L. (2007). Fear perception: Can objective and subjective awareness measures be dissociated? *J. Vis*. **7**, 10. https://doi.org/10.1167/7.4.10.

Tan, E. S. (2018). A psychology of the film, *Palgrave Commun*. **4**, 82. https://doi.org/10.1057/s41599-018-0111-y.

Tan, E., Doicaru, M. M., Hakemulder, F., Balint, K. and Kuijpers, M. M. (2017). Into film, in: *Narrative Absorption*, F. Hakemulder, K. Bálint, E. S. Tan and M. M. Kuijpers (Eds), pp. 97–118.: John Benjamins Publishing Company, Amsterdam, Netherlands. https://doi.org/10.1075/lal.27.06tan.

Thompson, R. and Bowen, C. J. (2009). *Grammar of the Edit*. Elsevier, Oxford, United Kingdom.

Thunell, E. and Thorpe, S. J. (2019). Memory for repeated images in rapid-serial-visual-presentation streams of thousands of images, *Psychol. Sci.* **30**, 989–1000. https://doi.org/10.1177/0956797619842251.

Timmermans, B. and Cleeremans, A. (2015). How can we measure awareness? An overview of current methods, in: *Behavioural Methods in Consciousness Research*, M. Overgaard (Ed.), pp. 21–46. Oxford University Press, Oxford, United Kingdom.

VanRullen, R., Busch, N. A., Drewes, J. and Dubois, J. (2011). Ongoing EEG phase as a trial-by-trial predictor of perceptual and attentional variability, *Front. Psychol.* **2**, 60. https://doi.org/10.3389/fpsyg.2011.00060.

Wang, Z., Healy, G., Smeaton, A. F. and Ward, T. E. (2016). An investigation of triggering approaches for the rapid serial visual presentation paradigm in brain computer interfacing, in: *2016 27th Irish Signals and Systems Conference (ISSC)*, Londonderry, pp. 1–6. https://doi.org/10.1109/ISSC.2016.7528466.

Wang, Y., Wang, Y., Liu, P., Wang, J., Gong, Y., Di, M. and Li, Y. (2018). Critical role of top-down processes and the push-pull mechanism in semantic single negative priming, *Consc. Cogn.* **57**, 84–93. https://doi.org/10.1016/j.concog.2017.11.007.

Wang, Y., Chen, J. and Ku, Y. (2021). Subliminal affective priming effect: Dissociated processes for intense versus normal facial expressions, *Brain Cogn.* **148**, 105674. https://doi.org/10.1016/j.bandc.2020.105674.

Wolf, W. (2004). Aesthetic illusion as an effect of fiction, *Style* **38**, 325–350. https://www.jstor.org/stable/10.5325/style.38.3.325.

Yang, J., Xu, X., Du, X., Shi, C. and Fang, F. (2011). Effects of unconscious processing on implicit memory for fearful faces, *PloS One* **6**, e14641. https://doi.org/10.1371/journal.pone.0014641.

Zerweck, I. A., Kao, C.-S., Meyen, S., Amado, C., von Eltz, M., Klimm, M. and Franz, V. H. (2021). Number processing outside awareness? Systematically testing sensitivities of direct and indirect measures of consciousness, *Atten. Percept. Psychophys.* **83**, 2510–2529. https://doi.org/10.3758/s13414-021-02312-2.