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Quicker, faster, darker: Changes in Hollywood film over 75 years

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Abstract. We measured 160 English-language films released from 1935 to 2010 and found four changes. First, shot lengths have gotten shorter, a trend also reported by others. Second, contemporary films have more motion and movement than earlier films. Third, in contemporary films shorter shots also have proportionately more motion than longer shots, whereas there is no such relation in older films. And finally films have gotten darker. That is, the mean luminance value of frames across the length of a film has decreased over time. We discuss psychological effects associated with these four changes and suggest that all four linear trends have a single cause: Filmmakers have incrementally tried to exercise more control over the attention of filmgoers. We suggest these changes are signatures of the evolution of popular film; they do not reflect changes in film style.

Keywords: film, motion, luminance, shot lengths.

1 Introduction

Popular American films penetrate nearly every aspect of contemporary Western life, and to an only somewhat lesser degree most all cultures of the world. Historically, there are powerful sociological, cultural, economic, and even political reasons for this, but we would also argue that Hollywood-style film has evolved so that filmmakers have more control over the attention of filmgoers (Smith 2006) and, in essence, the human mind. One source of evidence concerns the changing pattern of shot lengths. These patterns have incrementally approached the fluctuations of human attention as demonstrated in the laboratory (Cutting et al 2010; Gilden 2001). That is, human attention over time, as revealed by a series of reaction times (RTs) in a cognitive task, fluctuates in a pattern close to $1/f$, and increasingly, films have come to adopt near-$1/f$-shot-length fluctuations as well. That is, if one performs Fourier analysis on the serial patterns of RTs or of shot lengths, and then power analysis, one finds a complex array of self-similar sine waves whose periods are in the ranges of seconds, tens of seconds, minutes, tens of minutes, and longer, each wave growing in magnitude (power) proportional to its wavelength. Roughly, this means that the "height" of each wave (or amplitude, which is proportional to the square root of its power) is in strict proportion to its length, and the logarithmic units of power are the inverse of the logarithmic units of frequency ($= 1/f$). We

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and Gilden (2001) claim this pattern is a signature of the working human mind, and perhaps also a signature of what best captures our attention. No one can say definitively what causes these mental fluctuations, but it is clear that $1/f$ patterns are a hallmark for complexity, and they are found throughout the physical and social world (Newman 2005).

Nonetheless, film did not start out well meshed with human perceptual and cognitive systems. Instead, it has evolved slowly over the last 120 years. Early in the 20th century, frame presentation rates were increased to make the flicker of the successive images less aversive. At the same time cuts, dissolves, and fades were used to denote shots within the same scene, across scenes, and across larger film segments (acts), respectively. But later the use of dissolves and fades as visual cues to film structure was found to be largely unnecessary. Since the 1970s almost 99% of all transitions between shots in popular film are now cuts (Cutting et al 2011a). And, of course, sound was added to popular film in 1927, color by 1939, wide-screen imaging by the mid-1950s, and in the early 21st century there is at least a fourth attempt to introduce 3D as a major mode of presentation (see Salt 2006 and 2009 for histories).

Given all these changes, we think it makes sense to speak of an *evolution* for Hollywood film, one that increasingly makes presentational aspects of film either closer to what we perceive in the natural world (color, surrounding sound, enlarged images, etc) or aspects that capitalize on what has been discovered to be perceptually and cognitively acceptable (cuts, shot-reverse-shot composition and point-of-view editing, the optics of camera movements without feedback from eye movements, etc). This evolution would also appear to reflect a goal of Hollywood filmmakers: to increase their control over viewers' attention, and possibly to increase viewer engagement. If true, some long-term results of filmmakers' explorations exercising this control should be found in the changes along many perceptually relevant dimensions of film.

In this article we track four such trends over time. First, and following film scholars (eg, Bordwell 2006; Bordwell and Thompson 2004; Salt 2006; 2009), we measure the average shot lengths of films and find that the changes seen in our film sample are consistent with what they have reported. Second, we review and add to the data of Cutting et al (2011b) on the increase in the amount of motion and movement in films. Third, we measure the motion and movement within shots of different lengths and find a reliable change in pattern. And finally, we measure the luminance of each film. In all four cases we find a gradual, essentially linear change over 75 years.

2 The film sample and analyses

Previously, we (Cutting et al 2010; 2011a; 2011b) amassed 150 films for cinemetric analysis. We chose ten films from fifteen release years at five-year intervals from 1935 to 2005. All were English-language films, 139 were at least partly made in the United States, and 124 were in color. Films were selected from among those with the highest box-office gross for their given year or, before these statistics were systematically kept (beginning in 1977), from among the most rated films on the Internet Movie Database (http://www.imdb.com). They were also selected to represent five genres—action films, adventure films, animations, comedies, and dramas. Each film was downsampled so that frames were 256 x 256 pixels, and converted into both an .avi format to measure shot lengths and to a large array of jpeg files for frame comparisons across each film. The average film in this sample had about 1,100 shots and 165,000 frames. The online supplementary materials to Cutting et al (2010; 2011b) list the films and several of their cinemetric characteristics. For the current and ongoing project we added ten more films from 2010 using the same criteria, yielding a total of 160 films spanning 75 years. The most recent ten films are in a filmography given at the end of this article. All are

in English, all in color, and all at least partly made in the United States. When considering whole-film analyses we have excluded closing credits and the opening credits if they did not cover scenic shots. Generally, the historical transition from opening credits without scenic content to those with credits superimposed on the early shots of a film occurred around 1960.

Three physical measures of the 160 films are used in the analyses below, and one interaction between them. First, the average shot lengths (ASLs) of each film were determined. Segmenting films into shots has been a tedious and ongoing process, starting with the measurements by Cutting et al (2010). Subsequently, each film has been gone over several times by several individuals both with computer assistance and by hand. Although we occasionally find additional transitions previously missed, we are confident that we have found greater than 99% of them in each film.

Second, the median amount of motion and movement is reported, as determined by Cutting et al (2011b). Motion is the optical change created by moving objects, people, and shadows; movement is that change created by camera motion or gradual lens change (a zoom; see Gibson 1954). We calculated their combination by correlating next-adjacent frames along the length of each film—frames 1&3, 2&4, 3&5, ..., 40377&40379, ..., and so forth. We avoided adjacent frames (eg, 1&2, 2&3) because a number of the DVDs we obtained for these films were imperfectly digitized (the 24 frames/s rate in the analog film was not synchronized to the sampling rate of the DVD), creating frequent blends of adjacent analog frames in the digital version. We next took the median correlation of all frame pairs across the film, culling out those across cuts, and created a visual activity index (VAI, 1 – median r) for each film. In this manner the greater the VAI value the more motion, movement, and optical change in a film. The mean whole-film VAI for these movies was 0.05.

Third, we computed VAIs for each shot in each film. The purpose of these calculations was to determine the relative amount of motion and movement in shots of different duration and whether that relation had changed over the course of 75 years of popular film. Since both dimensions, shot length and VAI per shot, are strongly skewed, we transformed each. We took the logarithm of each shot duration, and because VAI is based on correlations, we used the r-to-z transform for VAIs. These transformations created roughly normal distributions along both dimensions for all films.

Finally, we computed the overall luminance of each film by finding the median luminance value of each frame, then averaging across frames. For the black-and-white films we simply worked with 8-bit pixel values of 0 (black) to 255 (white) from the jpegs; for the color films we first converted them to grayscale using the standard Matlab conversion, and then measured them in the same way. Median values for each frame were then given a reverse gamma transform of 1/2.2 before the whole-film mean luminance was calculated.

3 Results and preliminary discussion

Four results are shown in Figure 1. All of the data in Figure 1b, except for those of 2010 films, were reported in Cutting et al (2011b); the data of the three other panels are new to this article.

Consider first the trend in ASL from 1935 to 2010, shown in Figure 1a. We have plotted shot length on a logarithmic scale yielding a generally linear decline across time ($r = -.75$, $t(158)=14.3$, $p<.0001$), with ASLs of about 10 s in the 1930s and 1940s falling to below 4 s after 2000. The trend was reliable for all five genres ($rs< -.55$, $ts>3.3$, $ps<.01$). These overall data are consistent with Salt (2006; 2009), who measured more than 13,000 films over roughly the same period. Thus, these data serve to ramify the representativeness of our sample, and

the uniformity of the trend across genres. Among our films, *The Seven Year Itch* (1955, 26.2 s) had the longest ASL, and *Rocky IV* (1985, 2.2 s) the shortest.

It is clear that contemporary films have a quicker pace than those 50 years ago, although films from the end of the silent era had ASLs not much different from 1995 films (Salt 2009). Cuts constitute almost 99% of the transitions between shots in contemporary film (Cutting et al 2011a), and given that Mital et al (2010) have shown that cuts affect eye movements, generally causing saccades towards the middle of the screen, it is clear that more quickly paced films demand a reorientation of visual attention to a degree that older films do not.

Second, adding the 2010 films to the data of Cutting et al (2011b), we found a generally linear, 75-year trend of increased motion, movement, and optical change in popular films, as shown in Figure 1b ($r = .583$, $t(153) = 9.02$, $p < .0001$). As reported by Cutting et al (2011b), the increase in VAI is most pronounced for action and adventure films, but the trend is reliable for comedies and dramas as well. Excluded from this plot are five older cel-animated Disney films. Such films have different sections composed at 12 and at 24 frames/s (called "twos" and "ones"; see Salt 2006), and because of the former they have considerably more motion by our index than contemporary 24 frame/s animated films. For this reason no VAI trend was assessed for this genre. Among the films of our sample *Barry Lyndon* (1975, VAI = 0.008) had the optical change, and *Toy Story 3* (2010, 0.122) had the most.

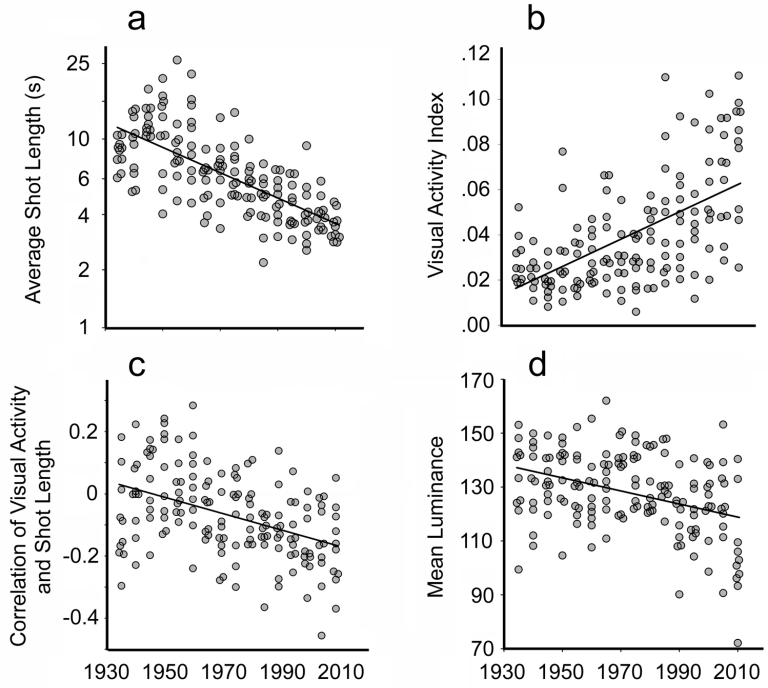

Figure 1. Four linear trends across 75 years of Hollywood film. Panel a shows the decreasing average shot lengths (ASLs) of films with the ordinate logarithmically scaled. Panel b shows the increase in the visual activity index (VAI) across the same period. VAIs are derived from correlating next-adjacent frame pairs across the length of each film, and then taking 1.0 − median r of the resulting distribution (except for year-2010 films, these data are from Cutting et al 2011b). Panel c shows the increasingly negative correlation between shot length and within-shot VAI for all shots in a given film. Finally, panel d shows the luminance of films over the last 75 years, with contemporary films becoming increasingly darker than their predecessors.

One might suppose that some of this change in VAI is due to the recent availability of smaller cameras that can be moved in more ways (eg, Bordwell 2006). However, this appears not to be the case. Salt (2009, page 283 & 371) tabulated seven kinds of camera-movement

shots (pans, tilts, pans with tilts, tracks, tracks with pans and tilts, cranes, and zooms) for 19 films released in 1999 and for 20 films released in 1959. Comparing these data reveals no patterned difference across the seven types between 1999 and 1959 ($\chi^2(6) = 8.43$, $p > .20$). Moreover and more importantly, the proportion of all shots with a moving camera actually *decreased* from 1959 (16%) to 1999 (6%).

Thus, our data show that films have clearly gotten faster, but on the basis of Salt's data it seems unlikely that the VAI increase in Figure 1b is due to camera movement; instead, it is likely due to the choice of filmmakers in depicting things that move. Much psychological experimentation has shown that motion and motion onsets capture our attention (eg, Abrams and Crist 2003; Hillstrom and Yantis 1994). The progression of filmmaking over the last 75 years would appear to have capitalized on this effect.

Third, Figure 1c shows how the correlation has changed between shot length and within-shot VAI as calculated for each of the 160 films and plotted by release year ($r = -.46$, $t(158) = 6.62$, $p<.0001$). As before, a 75-year pattern is clear. For the Hollywood studio era (here 1935 to 1960) there is no systematic relation between within-shot VAI and shot length—these factors are distributed independently of one another. However, for more recent films this is no longer the case. Instead, shorter shots tend to have more motion, and longer shots less motion per unit time. The overall trend makes sense for action films—action sequences in contemporary movies are often filled with short shots and nearly chaotic motion. But, interestingly, although action films demonstrate this effect over time ($r = -.54$, $t(33) = 3.73$, $p<.0007$), their trend is only modestly, and not reliably, stronger than those of comedies ($r = -.49$, $t(39) = 3.55$, $p<.001$) and adventure films ($r = -.40$, $t(19) = 2.0$, $p<.025$) in our sample. The general trend is not reliable for dramas ($r = -.24$) or animations ($r = -.03$), although both are in the same direction. Among the films of our sample, the short-shot/increased-motion correlation was strongest for *Revenge of the Sith* (2005, $r = -.46$, $p<.001$), and it was most strongly in the other direction for *The Apartment* (1960, $r = +.28$, $p < .001$).

We view this increasing inverse correlation of motion and shot length as an amplifying effect. That is, short shots likely increase viewer response to films and film segments, forcing observer eye movements to quickly reevaluate each new visual depiction and increasing heart rate and other bodily responses (Carruthers and Taggart 1973). Adding more motion to these short shots is likely to increase viewer response all the more. We suggest that this increasing correlation may help to couple attention to broader physiological responses. We also find it intriguing that the natural patterns of heart rate, like those of attention (Gilden 2001) and increasingly of film (Cutting et al 2010), follow a $1/f$ pattern (Saul et al 1988).

Fourth, consider luminance. In this context luminance is the overall brightness of film images about to be projected to the movie screen. Assuming generally uniform production processes in transferring analog films to DVDs, we assessed luminance by measuring the median 8-bit pixel value (0 to 255) in every frame throughout a film, then averaging those values. Results are shown in Figure 1d, where one can see that films have gotten incrementally darker over the last 75 years ($r = -.385$, $t(158) = 5.08$, $p<.001$). Over the span from 1940 to 1960 the films in our sample changed from black and white to color, but there was no average difference between these two film classes grouped across those release years (8-bit luminance: 132 vs 130 for black-and-white vs color films, respectively). The overall decline in luminance was reliable for all genres ($rs < -.25$, $ps<.05$) except animation, which has remained fairly constant and generally brighter than other genres. This may reflect the notion that animated films are largely made for families with young children, who may recognize that darkness is often associated with nonsalubrious events. The brightest film in our sample, however, is the adventure film *Those Magnificent Men in Their Flying Machines*

(1965, 8-bit luminance = 162.0), and by far the darkest is another adventure film *Harry Potter and the Deathly Hallows, Part 1* (2010, 72.1).

There are likely several reasons for the long-term luminance decrease. First, analog film and its digital successor have increased their dynamic range, allowing for darker darks in a given image. Second, and also due to film stock, studio-era films needed to be shot under very bright lights, whereas for contemporary films that is no longer necessary (Salt 2009). And third, a darker film in a dark theater allows for greater dynamic contrast, which in turn allows for better control over viewers' attention (Lin and Yan 2011, Smith (2006), and the potential of viewers seeing a film even more convincingly as an invisible window into the world in which the narrative takes place.

To complete the inventory of possible comparisons among shot lengths, motion, and luminance, consider two more. First, the correlation across films between VAI and luminance was small ($r = -.16$, $t(158) = 2.05$) and not reliable when corrected for multiple comparisons across the three variables of interest. Second, the trend over time of changes of shot-length and within-shot luminance was also not reliable ($r = -.12$).

4 General discussion

Compared with painting, architecture, music, poetry, literature, theater and other art forms less dependent on technology, film is quite new. Given this, it is more straightforward to document how film as an art form has changed. We suggest that, with these evolved changes, filmmakers are exercising more control over a viewer's attention. Moreover, it may be that film has become better adapted to human perceptual and cognitive processes. Our purpose in this article has been to outline four such changes in the physical variables of popular film over the last 75 years, where these variables have particular perceptual import—abrupt transients, motion, and luminance. Clearly, the transients created by cuts across shots, the motion that occurs within shots, and a film's luminance are aspects of film that are picked up by the visual system as a viewer watches and comprehends a film. The mechanisms for their detection are quite well understood (Adelson and Bergen 1985; Ögmen and Breitmeyer 2006; Peli et al 1996), and we have nothing to add in this regard. The mechanisms underlying the trends seen in Figure 1, however, cannot be psychological or perceptual.

The three individuals that have the most control over the final appearance of a film are the director, the cinematographer, and the editor. The 160 films we have analyzed had more than 400 different such individuals, and each of them often led teams of considerable size. Thus, popular films are a collective and collaborative product, and the causes for the general changes in film over time as shown in Figure 1 can only be sociological, even cultural. That is, through the cultural transmission and dissemination of filmmaking practices, through experimentation and technological innovation, and through continual inspection and evaluation of their results, the relatively small community of filmmakers has gradually changed their craft, changed their understanding of how to make films, and exploited perceptual variables of interest. Clearly, a backdrop of their own visual capabilities, and what they can assume for their viewers, has guided filmmakers' creation of their products. Put more directly, shorter shots, increased motion, the coupling of shot lengths and motion, and decreased luminance all appear to serve the filmmaker to better control the eye movements and the attention of the viewer (see also Smith 2006). These might also increase viewer engagement.

Finally, it should be noted that the changes along all four dimensions—ASL, VAI, shot-VAI by ASL, and luminance—were essentially linear. Much has been made about possible cyclical changes in the arts (eg, Carbon 2011; Martindale 1990), and what might be inferred to be changes in style. The appearance of four linear and independent changes strongly

suggests that cyclicity and style change are not involved here. Instead, these changes reflect an evolution of Hollywood film.

5 Conclusions

The physical form of popular film has changed over the last 75 years and seems likely to continue to do so. Here we have documented four linear changes. We believe that all of them have been created by filmmakers seeking to control the attention of their viewers, and possibly to enhance viewer involvement in film. These four dimensions—shot length, motion, the coupling of shot length with motion, and luminance—by no means exhaust the potential changes that might be found in popular film over this span, but they do add to our cinemetric knowledge of how films have been constructed and how perceptually relevant variables have been harnessed to produce cultural products.

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