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Attention and the Evolution of Hollywood Film

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Abstract

Reaction times exhibit a spectral patterning known as 1/*f*, and these patterns can be thought of as reflecting time-varying changes in attention. We investigated the shot structure of Hollywood films to determine if these same patterns are found. We parsed 150 films with release dates from 1935 to 2005 into their sequences of shots and then analyzed the pattern of shot lengths in each film. Autoregressive and power analyses showed that, across that span of 70 years, shots became increasingly more correlated in length with their neighbors and created power spectra approaching 1/*f*. We suggest, as have others, that 1/*f* patterns reflect world structure and mental process. Moreover, a 1/*f* temporal shot structure may help harness observers' attention to the narrative of a film.

Keywords

attention, cinema, film, visual momentum, 1/*f*

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What grabs people's attention? This question has been central to psychological research for a long time (James, 1890; Luck & Vecera, 2002), and answers are myriad. Once observers' attention is grabbed, can they hold it there? Studies of vigilance show that they generally cannot (Parasuraman, 1986). Attention vacillates. As James (1890) noted: "There is no such thing as voluntary attention sustained for more than a few seconds at a time" (p. 421). People's minds wander.

The study of minds' restlessness (Smallwood & Schooler, 2006) has never been mainstream in empirical psychology. To be sure, Verplanck, Collier, and Cotton (1952) demonstrated attentional fluctuations during a psychophysical task, and Antrobus (1968) showed that performance generally improved in signal detection as presentation rate increased, a finding implying less mind wandering at faster rates. But attentional fluctuations generated little interest. To gain interest, the waxing and waning of attention and performance needed a new measurement tool and a snappy result allied with the harder sciences. These were provided by Gilden, Thornton, and Mallon (1995), who analyzed reaction times as a fluctuating time series and found what is referred to as a 1/*f* pattern, in which power is inversely related to frequency. Gilden (2001) suggested that the ebb and flow of reaction time performance is caused by cognitive effects that vary at different time scales, creating the 1/*f* structure.[1]

In engineering, physics, biology, economics, and now perhaps psychology, 1/*f* patterns are ubiquitous. Their structure, however, is sometimes opaque to intuition. Consider the variation in a complex, one-dimensional signal across time or space. This signal can be analyzed by Fourier analysis, which decomposes it into sine waves of different frequencies, amplitudes, and phases. The potential patterns in the relations among the frequencies and amplitudes create a family of "noises," some of whose members occur commonly in nature. These are often called white, brown, and pink noise, and all are defined by the relation between the frequency and power (proportional to the square of the amplitude) of their components. By convention, log frequency is plotted against log power, creating a spectrum. In such plots, white ($1/f^0$) noise has a flat spectrum, with equal power at all frequencies. Brown ($1/f^2$) noise, named after Brownian motion, has power that falls linearly and steeply with increasing frequency. Pink ($1/f^1 = 1/f$) noise is intermediate, with power falling linearly and inversely proportionally to frequency. Together, brown, pink, and other non-white spectra are often called colored noises.

For our purposes, 1/*f* structure can be thought of as a pattern of waves that course through a temporal signal and are independent in phase. The "height" of each component wave varies inversely with frequency (1/*f*) and directly with wavelength

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(λ). That is, small fast waves are accompanied by other waves that grow larger as they increase in wavelength. If the wavelength is doubled (or the frequency halved), the power is doubled.

The causes for $1/f$ patterns across the sciences are unclear, but it is now increasingly accepted that there are many such causes (Newman, 2005). In vision, Field (1987) found $1/f$ spectra in natural scenes, and Graham and Field (2007) found them in artworks. These results reflect the structure of the human visual system. Again, Gilden et al. (1995)—as well as Pressing and Jolley-Rogers (1997) and Van Orden, Holden, and Turvey (2003)—found $1/f$ spectra in reaction times, and Monto, Palva, Voipio, and Palva (2008) found evidence for their neurological underpinnings. These results seem to reflect the organization and structure of the human mind.

Hollywood film might seem far removed from, and not amenable to, this kind of analysis, but we thought not. The $1/f$ temporal patterning has been found in speech and music (Voss & Clarke, 1975), so film seemed to be another good place to look. Further, we thought we might be able to trace its evolution in film.

On Film and Theory

Film is the only major art form to have begun and matured within the past 125 years. This fact allows exploration of its evolution in ways not possible in other arts. Indeed, considerable scholarship has documented changes from the earliest films and their short, episodic displays of sneezes, dances, and boxing; to slightly longer films with modest story structure after 1900; through the soundless works of Griffith, Chaplin, Keaton, and other directors into the 1920s; to the first feature films with sound after 1927; to film adaptations of books, plays, and musicals; and later to film noir, the new wave, the movie brats, and digital cinema (e.g., Bordwell, 2006; Bordwell, Staiger, & Thompson, 1985; Salt, 1992, 2006).

Twentieth-century film theory was dominated by psychoanalytic, Marxist, and feminist approaches. Cognitive film theory, which has focused on linkages between the mind and physical attributes of film, has been less well established (but see Anderson, 1996; Carroll & Bever, 1976; Hochberg & Brooks, 1978b; Smith, 2006). Our approach is very much in this vein, and falls under the rubric of cinemetrics. Here, we focus on films in Hollywood style, also called invisible style (Bordwell et al., 1985; Messaris, 1994). This style—differing from those of documentaries, TV newscasts, sitcoms, music videos, and most of what is called art film—is designed to suppress awareness of the presentational aspects of the film while promoting the narrative.

The units of film are the act, the sequence, the scene, the shot, and the single frame. A film typically has four acts of more or less equal length, and their narrative structure has a long history in guides to writing screenplays (Thompson, 1999). A scene is a series of shots depicting a given time and place, but sometimes scenes move continuously through space and time, creating larger units called sequences (as in chase sequences). Shots are continuous runs of frames from a particular point of view of the camera; they are separated by transitions of various kinds—cuts, dissolves, fades, wipes, and others. Cuts—abrupt discontinuities from one frame to the next—make up more than 99% of transitions in contemporary film.

Our unit of investigation was the shot. Shots are the smallest film units to which viewers are asked to direct their attention. Shot form is sculpted by directors, cinematographers, and film editors. The purpose of that form is to control the viewer's eye fixations and attention, and filmmakers do this fairly well (Smith, 2006). Shot relations are sculpted by the film editor to promote the narrative (Dmytryk, 1984; Ondaatje, 2004), and these relations create in the viewer what Hochberg and Brooks (1978a, 1978b) called visual momentum, the impetus to gather visual information. In other words, the rhythm of shot sequences in film is *designed* to drive the rhythm of attention and information uptake in the viewer. Perhaps the success of these rhythms reflects what Kael (1965) meant by "losing it" at the movies.

Film Choice, Shot Parsing, and Analysis

We chose 150 films, 10 released in each of 15 years, every 5 years from 1935 to 2005. The Supplemental Material available on-line provides the complete list. Assembled from information in several on-line databases, the films from 1980 onward were among the highest grossing of their year and the earlier films were among those with the largest number of viewer ratings on the Internet Movie Database (IMDb; http://us.imdb.com). The films were also chosen, as best we could, to represent five genres—action, adventure, animation, comedy, and drama—although their distribution could not be uniform because of vagaries in Hollywood production and changes in social milieu and viewers' taste. Genres were defined by the first-designated category for each film on the IMDb. After selection, films were manipulated from files in *.avi format stripped of their audio track. Each frame was stored as a 256- × 256-pixel jpeg file. Excluding all trailing credits and beginning credits without scenic content, the mean film length was 114 min (SD = 26 min), entailing a mean of about 165,000 jpeg files.

We needed to divide the films into shots, but we were unimpressed with purely digital methods. Cut-finding algorithms often confuse motion across frames within a shot with spatial discontinuities across shots. They also do poorly with fades, dissolves, and wipes, which are common in films made before 1960 (Carey, 1974). Over, Ianeva, Kraaij, and Smeaton (2007) noted that the best cut-detection algorithms have hit and false alarm rates of about 95% and 5%, respectively ($d' \sim 3.3$), and the best dissolve detectors have corresponding rates of about 80% and 20% ($d' \sim 1.7$). Such performance was inadequate for our purposes, so we devised a three-stage MATLAB-based (MathWorks, Natick, MA) system.

The first stage found candidate cuts and other transitions by tracking frame-to-frame changes in histograms of luminance values within 64 cells (in an 8 × 8 array, each cell with 32 × 32 pixels). It also found candidate dissolves and fades by tracking monotonicity of changes in those cells across traveling windows of 12 frames. For each candidate transition, the second stage presented the user with an array of six static images—six images before and after a candidate cut or six images during a candidate dissolve, fade, or wipe. The user then accepted or rejected the candidate, and the process continued with the next. If the user felt that content of the six images was discontinuous from one candidate transition to the next, he or she flagged the region. The third stage allowed the user to inspect these flagged regions for possible missed transitions. With this interface, we obtained a hit rate of 99.6% and a false alarm rate of 0.2% ($d' \sim 5.5$), using the frame-by-frame analysis of two films (*The Revenge of the Sith*, 2005; *Spies Like Us*, 1985) as our criterion. The number of shots per film ranged from 231 (*Seven Year Itch*, 1950) to 3,099 (*King Kong*, 2005), with a mean of 1,132. Counting machine and operator time, this process—going from *.avi to jpeg files, finding candidate transitions, and verifying them—took from about 15 to 36 hr per film.

In the psychological literature on time series analysis, there is a debate over whether local (autoregressive) or global ($1/f$) models better capture structure in data (e.g., Farrell, Wagenmakers, & Ratcliff, 2006; Thornton & Gilden, 2005). Thus, we chose to investigate both models, although, as we demonstrate, they are closely related. Shot lengths were analyzed using partial autocorrelation and power analyses, which allowed us to look for local patterns (shot-to-shot relations) and global patterns (whole-film editing profiles), respectively. Schils and de Haan (1993) performed a similar local analysis on sentence lengths in texts, and Salt (2006, p. 396) provided some piecemeal, local analyses of a number of films. In addition, Richards, Wilson, and Sommer (1994, Experiment 4) analyzed portions of four films in a manner related to our global analysis.

Results and Preliminary Discussion

Relations measured locally

Autoregressive analysis allows one to inspect the relations among a given set of shots, beginning with adjacent shots and then expanding to increasingly distal shots. We use the term Shot 0 to refer to a shot of focal interest; every shot up to near the film's end was analyzed as Shot 0. The autocorrelation of the length of a Shot 0 with itself (Lag 0) is always 1.0; autocorrelations of the length of Shot 0 with the lengths of Shots 1 (Lag 1) and more distal shots are of more interest. The correlation of Shots 0 and 1, r_{01}, was the first value inspected. If it was statistically reliable—greater than a positive bound ($2/\sqrt{n}$, where n is the number of shots)—we then considered the correlation between Shots 0 and 2 with intermediate effects involving Shot 1 partialed out, $r_{02.1}$. Reliable correlations r_{01} and $r_{02.1}$ support an autoregressive model called AR(2) (Box, Jenkins, & Reinsel, 2008; Chatfield, 2004). For descriptive purposes, we considered every incremental positive partial correlation as long as previous values remained positive and above criterion. In this context, reliable correlations $r_{03.12}$, $r_{02.1}$, and r_{01} support an AR(3) model. In our database, *Rocky IV* (1985) exhibited the most distal relations. Partial correlations for Shots 0 through 7, $r_{07.123456}$ and its kin, suggested an AR(7) model for that film.

The lag-incremented, reliable partial autocorrelations for all films were determined. This analysis yielded 150 cardinal-valued AR indices. Those indices were correlated with release years, $r = .44$, $t(148) = 6.01$, $p < .0001$, 95% confidence interval (CI) = [.27, .54]. However, there can be much noise in partial-autocorrelation functions, as Figure 1 shows, and films with fewer shots are penalized; their bounds are higher, which tends to generate smaller AR indices. Thus, we fit each function out to Lag 20 with a negative exponential function ($1/[\text{lag} + 1]^{\beta}$; average root-mean-squared deviation = .043, $SD = .006$) and then assessed its intercept with a positive bound (.065) based on the mean number of shots in all films. This procedure yielded a continuous rather than discrete autoregressive index; the values of this index are shown in Figure 2a. The correlation of this new index with release year was reliable, $r = .43$, $t(148) = 5.89$, $p < .0001$. The best, median, and worst of the 150 fits to the negative exponential function are shown in Figure 1. The increase across years that is evident in Figure 2a is not an artifact of decreases in mean shot length in films over this span of time (Bordwell, 2006; Bordwell et al., 1985; Salt, 1992, 2006). When shot durations for each film were log-transformed and the autoregressive analyses repeated, the correlation remained essentially unchanged, $r = .45$.

These results suggest that Hollywood film has become increasingly clustered in packets of shots of similar length. For example, action sequences are typically a cluster of relatively short shots, whereas dialogue sequences (with alternating shots and reverse-shots focused sequentially on the speakers) are likely to be a cluster of longer shots. In this manner and others, film editors and directors have incrementally increased their control over the visual momentum of their narratives, making the relations among shot lengths more coherent over a 70-year span.

Figure 2b shows the pattern of these correlations for five genres of film—action, adventure, animation, comedy, and drama. Clearly, the action film, which has grown more popular in recent decades, is the leader in showing this increasing pattern of coherence. Nonetheless, selected individual films from other genres also show relatively large modified autocorrelation indices—*Popeye* (1980), comedy: 3.64; *Five Easy Pieces* (1970), drama: 3.38; *Swiss Family Robinson* (1960), adventure: 4.22; *Anchors Aweigh* (1945), comedy: 3.76; *Santa Fe Trail* (1940), drama: 4.65. (See the Supplemental Material for results for the other films.)

Relations measured globally

Gilden et al. (1995; see also Gilden, 2001) noted that cognitive emissions of $1/f$ noise are blended with white noise and devised

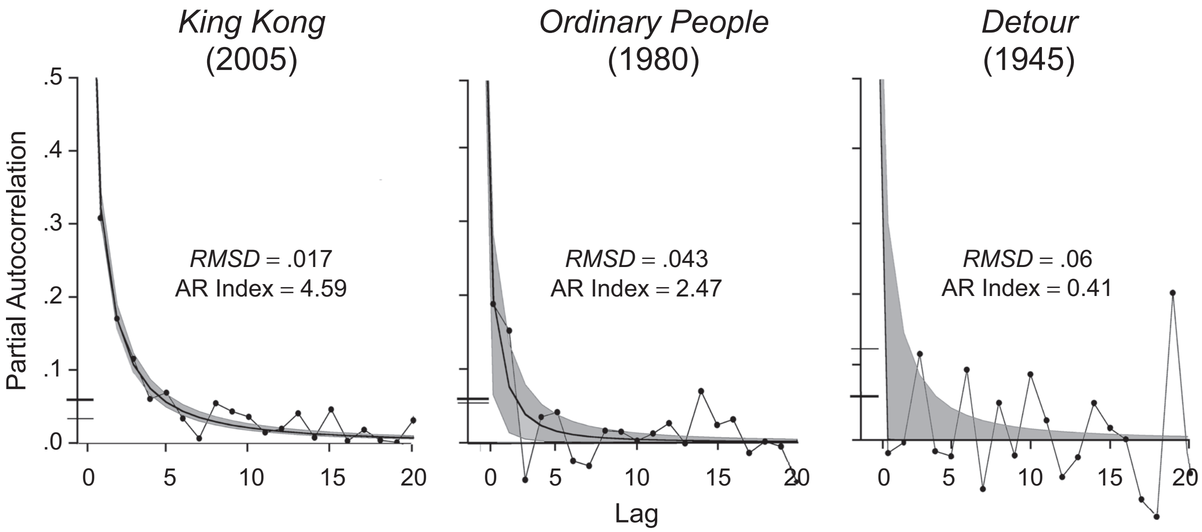

Fig. 1. Raw partial autocorrelations of three films as a function of lag (the ordinal distance between shots whose lengths are being compared). The thick lines represent the fits of a negative exponential function $(1/[\text{lag} + 1]^{\beta})$; that for *Detour* is thrust up against the ordinate and so cannot be seen. From left to right, the panels show results for films with the best, median, and worst fits across the 150 films. The ordinate is truncated because the Lag 0 value of 1.0 is uninformative. Gray areas indicate 95% confidence intervals around the best fit, determined by bootstrap. The additional tick marks on the ordinate indicate the upper bound of significant partial correlations; the thick mark is based on the mean number of shots across all films, and the thin one is based on the number of shots in the given film. Our modified autoregressive index (AR index) for each film (see Figs. 2a and 2b) was determined by the intersection of the exponential function and the mean upper bound for all films. *RMSD* is the root-mean-squared deviation between the fitted function and the raw data.

a model to treat data as a mixture of the two. Here, we follow this lead and focus on the colored-noise component of films; we found no systematic differences for white-noise components across years or genres. After transforming shot lengths in each film to a unit normal distribution ($M = 0$, $SD = 1$), we adapted Gilden's analyses to the shot sequence. Composite power spectra (see Thornton & Gilden, 2005, Appendix A) are best calculated within traveling windows whose lengths are powers of 2. Given the variability in Fourier calculations, we followed a conservative procedure: For each film, we determined the integer n such that the number of shots was between 2^n and 2^{n+1} and then carried out power analyses for traveling-window lengths up to 2^{n-1}. Thus, for a film of 1,500 shots (between 1,024 and 2,048, 2^{10} and 2^{11}), we calculated power in windows up to 512 (2^9) shots. The hybrid model of $1/f^{\alpha}$ and white noise was then fit to the composite spectrum of each film, and the slope (α) of the colored noise determined. Model fits to the 150 power spectra were generally good (average root-mean-squared deviation = .08, $SD = .05$). Figure 3 shows examples of good and poorer fits to films at three different general slope values.

Notice that for *The Revenge of the Sith* (2005), the curvilinear spectrum is relatively flat in the range of 2 to 4 shots (out to a window of about 15 s for that film), which suggests that white noise is dominant in that range. For *Die Hard 2* (1990), this flatter part of the curved spectrum (and white-noise dominance) extends out to the range of 32 shots (a window of about 100 s for that film). White noise is less apparent, but by no means absent, in the other four films. Curvilinearity becomes salient only at steeper slopes, and it is also seen in reaction time data (Gilden & Hancock, 2007), in which the window of white-noise dominance is determined partly by the intertrial interval (see also Antrobus, 1968).

The slopes for all 150 films are shown in Figure 2c. Dispersion is again considerable, but slopes steepened linearly from 1935 to 2005, $r = .19$, $p < .01$, 95% CI = [–.03, .31]. Nonetheless, a first-order polynomial fits the data modestly better, $r = .28$, $p < .0002$. Interestingly, among our films, four films noir (*Detour*, 1945; *Mildred Pierce*, 1945; *Asphalt Jungle*, 1950; *Sunset Boulevard*, 1950) have a mean slope of only 0.09, which suggests no pattern in the composition of shot lengths. Among other related films that might be of general interest, the six Alfred Hitchcock films (*The 39 Steps*, 1935; *Foreign Correspondent*, 1940; *Rebecca*, 1940; *Spellbound*, 1945; *The Trouble with Harry*, 1955; and *To Catch a Thief*, 1955) have a mean slope of 0.53; the two James Bond films have slopes of 0.41 (*Thunderball*, 1965) and 0.82 (*GoldenEye*, 1995); and the two *Star Wars* films have slopes of 0.98 (*The Empire Strikes Back*, 1980) and 1.14 (*The Revenge of the Sith*, 2005). (Again, see the Supplemental Material for results for the other films.)

Figure 2d shows the slopes by genre and exhibits a pattern similar to that for the modified autoregressive indices (Fig. 2b). Action films have the steepest mean slope (closest to $1/f$), followed by adventure, animation, comedy, and drama films. However, some individual non-action films have slopes approaching $1/f$—*The Perfect Storm* (2000), adventure: 0.90; *Pretty Woman* (1990), comedy: 0.92; *Rebel Without a Cause* (1955), drama: 0.88; *Cinderella* (1950), animation: 0.95; *The 39 Steps* (1935), drama: 0.93.

Finally, given that autoregression and power analysis are related (the Fourier transform of the autocorrelation function

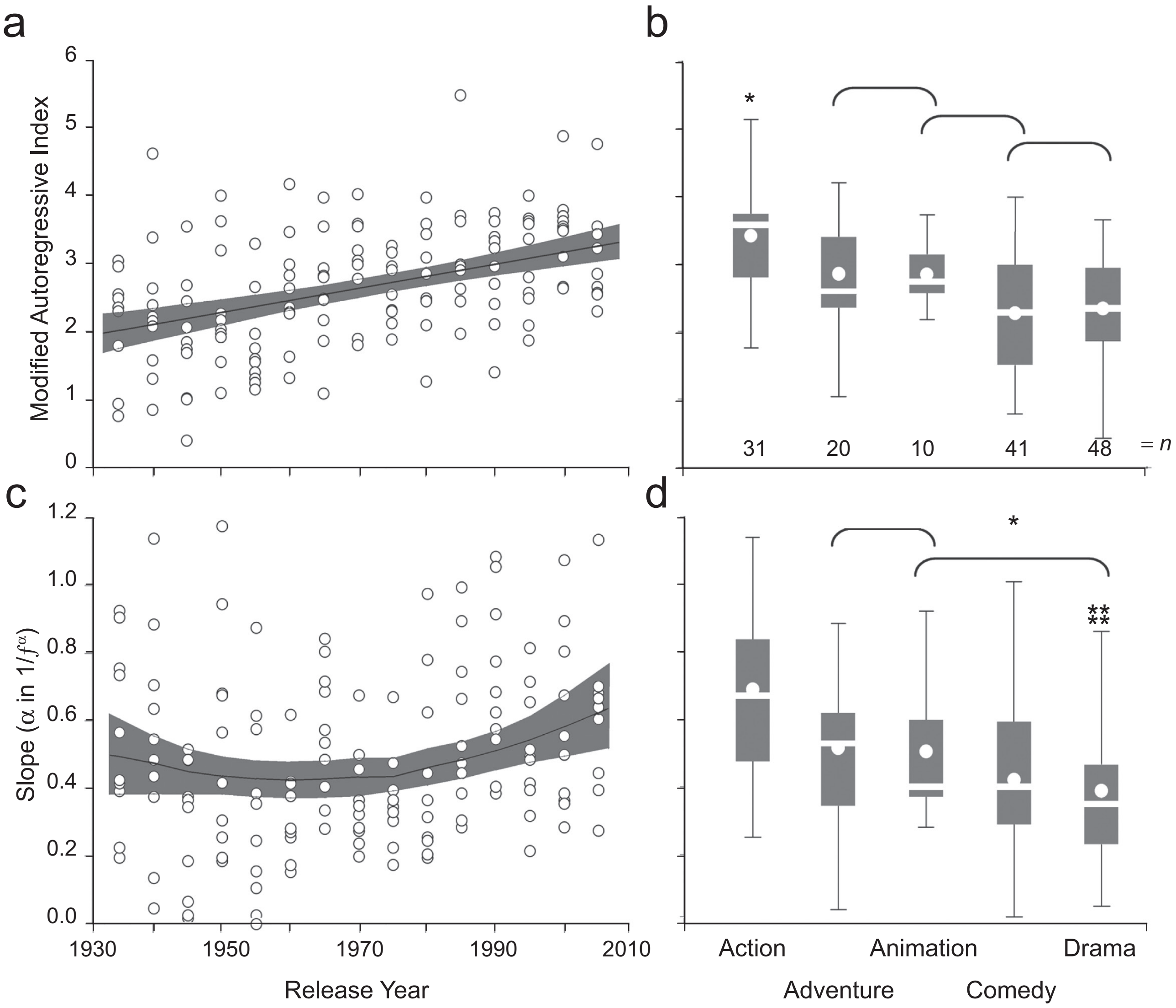

Fig. 2. Results of the local (top row) and global (bottom row) analyses. The scatter plots present (a) autoregressive indices and (c) slopes of the power spectra for shot sequences as a function of release year. The box plots present (b) autoregressive indices and (d) slopes of the power spectra for shot sequences as a function of genre. A linear fit is shown for the autoregressive data in (a), and a first-order polynomial fit is shown for the slope data in (c). Gray areas indicate 95% confidence intervals for the regression lines as determined by bootstrap; the regression lines are the 50% percentile of regression fits after bootstrap. In the box plots (b and d), the gap and circle represent the median and the mean, respectively, for each genre. Each two-part box represents the interquartile range; the whiskers indicate the entire range, unless there are outliers (> 1.5 × interquartile range—here, above the third quartile), which are indicated by asterisks. Horizontal brackets span genres that are not statistically different from one another (no correction for multiple comparisons). See the text for explanations of the modified autoregressive index and the slope index.

is the power spectrum), one would expect the modified autoregressive indices and slopes to be correlated. Indeed, they are ($r = .52$). However, for films with steep slopes, the local effects are buried in the white-noise-dominated end of the spectrum. Our interest resides more strongly in the $1/f$ pattern because of its possible connection with the structure of attention.

General Discussion

Our results suggest two new ways to look at cinema. First, the history of Hollywood film is often parsed into a classical period before 1960 and a postclassical period thereafter (e.g., Bordwell et al., 1985). Bordwell (2006) was careful to trace continuities across those periods, and the linear fit to the modified autoregression results here (Fig. 2a) supports this idea. However, a first-order polynomial fit of the power slopes (Fig. 2c) suggests that 1955 to 1970 was the nadir of whole-film shot organization, with the films of 1935 and 1940 having somewhat greater and more varied slopes, and only those after 1980 generally approaching a $1/f$ profile.

Second, film theorists have noted that physical attributes of film have evolved, but although some have stated that shot lengths have gotten shorter, none have suggested a continuing direction for change. We suggest that over the next 50 years or

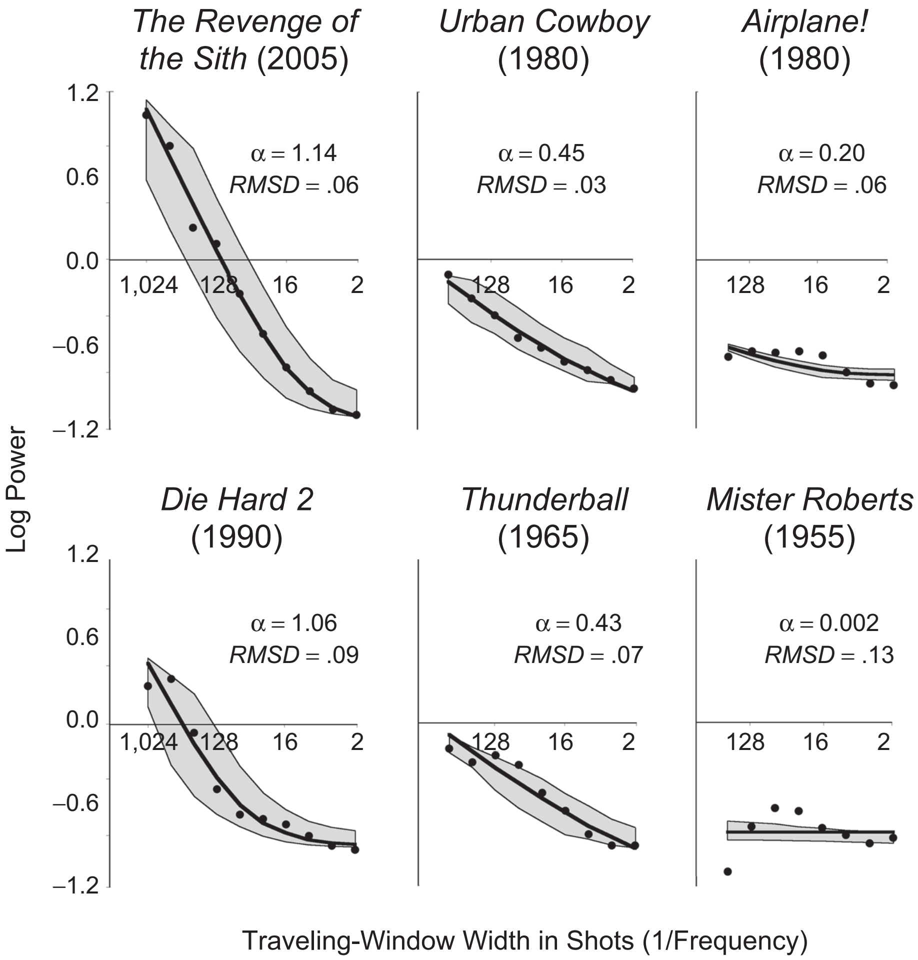

Fig. 3. Log-power as a function of width of the traveling window in six films. The thick lines indicate the fits of $1/f^{\alpha}$ and white noise to the composite power spectra. The six examples illustrate good (upper panels) and poorer (lower panels) fits at slopes (α) near 1.0 (left panels), near 0.5 (middle panels), and near 0.0 (right panels). Gray areas represent the interquartile confidence intervals as determined by bootstrap. Traveling-window width is the size of the successive, maximally overlapping windows within which Fourier analysis was done before mean power was computed for each point in the composite spectrum. The slope of the fitted function was used to index each film, as shown in Figure 2. *RMSD* is the root-mean-squared-deviation between the fitted function and the raw data.

so, and with action films likely leading the way, Hollywood film will evolve toward a shot structure that more generally matches the 1/*f* patterns found elsewhere in physics, biology, culture, and the mind.

Some caveats are in order. First, given our results, one might assume that viewers like better those films with a shot structure closer to a 1/*f* pattern. However, this is not the case. Many viewers ($M \sim 3 \times 10^4$, maximum $\sim 2 \times 10^5$, and minimum $\sim 10^2$, as assessed on February 28, 2009) rated these 150 films on the IMDb, and their ratings do not correlate with film slopes ($r = –.089$, n.s.).[2] There are likely many reasons for this, but we think they converge on two facts: (a) Our data are not about film narratives, but rather are about the presentation of film narratives, and (b) film narratives can be presented in many ways. This study collapsed across the work of more than 500 different directors, cinematographers, and film editors, all with their particular styles, preferences, and skills. This leads to our second caveat: In no way do we claim that there is any intention on the part of filmmakers to develop a 1/*f* film style, even if they knew what that might be. Instead, we claim that, as explorations and crafting of film have proceeded for at least 70 years, film narrative has fallen naturally into 1/*f* shot structure as the myriad of other considerations in filmmaking have played against each other in shaping film form. Good storytelling is the balancing of constraints at multiple scales of presentation. Thus, we view 1/*f* film form as an emergent, self-organizing structure (Gilden, 2001; Van Orden et al., 2003), not as an intentional one.

How might 1/*f* shot patterns entrain attention over periods of 1 to 3 hr? Current theories of attention provide little guidance. Most concern instants, not longer stretches of time. Accounts of mind wandering offer some help. Mind wanderings can be viewed as lapses of executive control as unrelated stimuli (external and internal) compete for attentional resources

(Smallwood & Schooler, 2006). Such vacillations will be minimal when information load is high and will increase when information load is lowered (Antrobus, 1968). But is the task of the filmmaker solely to keep information flow and visual momentum (visual information uptake) sufficiently high to ward off the mind's natural restlessness? Not likely. Otherwise, all films would be composed of unremittingly short shots.[3] Instead, it seems more likely that a temporally scaled theory of attention should be linked, as Gilden (2001) suggested, to a view that the mind is a complex system with interrelated parts that interact over multiple scales of time—milliseconds, seconds, minutes, hours, and intervals in between. As such systems operate, they have a tendency to produce $1/f$ patterns.

In conclusion, the endogenous wavering of attention has a $1/f$ temporal structure (mixed with white noise; Gilden, 2001). In addition, film shots are designed to capture and focus attention (Smith, 2006), and film editors design shot patterns with care, generating a visual momentum in the viewer, who tracks the narrative. This study has now demonstrated that the shot structure in film has been evolving toward $1/f$ spectra (again, mixed with white noise). Thus, we suggest that the mind can be "lost" (Kael, 1965) most easily in a temporal art form with that structure. That is, setting the actual narrative aside, perhaps being engrossed in a film is, in part, to allow its $1/f$ temporal structure to drive the mind exogenously.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Supplemental Material

Additional supporting information may be found at http://pss.sagepub.com/content/by/supplemental-data

Notes

1. When discussing cognitive emissions of a $1/f$ signal, Gilden (2001) focused on memory and interference. Without denying their importance in this context, we choose to focus on attention. Interference and facilitation from past events have equal play in the domains of memory and attention (e.g., Cowan, 1995).

2. This is a partial correlation with release year of the film factored out. Older films, perhaps because some are regarded as "classics," tend to have higher ratings, $r = -.37$. The simple correlation between slope and rating is –.14.

3. In an early scene in *Wedding Crashers* (2005), shots are synchronized to the rhythm of a remix of the Isley Brothers' song "Shout." For a 90-s stretch, each shot is about 1-s long. The sequence is amusing, even riveting, but clearly could not be sustained.

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