# A Ticket for Your Thoughts: Method for Predicting Content Recall and Sales Using Neural Similarity of Moviegoers

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Skilled advertisers often cause a diverse set of consumers to feel similarly about their product. We present a method for measuring neural data to assess the degree of similarity between multiple brains experiencing the same advertisements, and we demonstrate that this similarity can predict important marketing outcomes. Since neural data can be sampled continuously throughout an experience and without effort and conscious reporting biases, our method offers a useful complement to measures requiring active evaluations, such as subjective ratings and willingness-to-pay (WTP) scores. As a case study, we use portable electroencephalography (EEG) systems to record the brain activity of 58 moviegoers in a commercial theater and then calculate the relative levels of neural similarity, cross-brain correlation (CBC), throughout 13 movie trailers. Our initial evidence suggests that CBC predicts future free recall of the movie trailers and population-level sales of the corresponding movies. Additionally, since there are potentially other (i.e., non-neural) sources of physiological similarity (e.g., basic arousal), we illustrate how to use other passive measures, such as cardiac, respiratory, and electrodermal activity levels, to reject alternative hypotheses. Moreover, we show how CBC can be used in conjunction with empirical content analysis (e.g., levels of visual and semantic complexity).

*Keywords*: cognitive neuroscience, consumer memory, neural similarity, field experiments, electroencephalography (EEG), cross-brain correlation (CBC)

Communication has enabled our species to thrive beyond all others since our strengths in groups surpass those as individuals. Information exchange affords collective knowledge, abilities, and social structures that comprise a whole that exceeds the sum of our individual brains (Harari 2014). Since efficient communication (from Latin *communicare*, meaning "to share" or "make common") requires a way of translating ideas from one individual to another, neuroscientists have begun to study the parallels between multiple brains experiencing the same stimulus (Furman et al. 2007; Hasson et al. 2004, 2008; Regev et al. 2013). These studies reveal that brains act similarly while processing certain stimuli. These findings, in turn, raise questions about the nature and implications of shared neural responses. These pioneering studies differ from the existing cognitive neuroscience literature, which has traditionally focused on the activity within individual brains. Classically, neuroscientists have been trying to locate a set of brain regions that are uniquely activated when participants process sensory content (Yamasaki, LaBar, and McCarthy 2002). While some of these studies have offered evidence of networks relating to drifts in attention (Esterman et al. 2012; Mason et al. 2007), the field has yet

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to identify a clear, finite set of brain regions whose activity modulates when an individual processes content. Thus, we are intrigued by recent efforts to measure the similarity between multiple brains when an idea is shared, and we propose the use of such a metric, which we refer to as cross-brain correlation (CBC), as a predictor of consumer persuasion and behavior. In this work, we detail the requirements by which a tool of this nature can be applied in the context of consumer research. To illustrate the usage of our methodology in a commercial setting (viz., a movie theater), we present a case study in which we use portable electroencephalography (EEG) systems to record consumers' moment-to-moment brain activity while viewing audiovisual content (viz., movie trailers) and then calculate CBC across the study audience as a potential correlate of content recall, attitudes, and population-level sales.

Conceptually, observers experiencing the same content will necessarily share in basic feature processing; therefore, the marginal degree of resemblance between multiple brains presumably reflects parallels in higher-order information processing, such as interpretations, predictions, emotional responses, memory formation, and selective attention to certain aspects of the stimulus. Within individuals, many of these constructs have been studied extensively using tools such as EEG (Charland et al. 2013), functional magnetic resonance imaging (fMRI) (Falk, Berkman, and Lieberman 2012; Poldrack 2008), eye tracking (Teixeira et al. 2010), and biometric measures (Ohme, Matukin, and Pacula-Lesniak 2011). Substantial research has also been conducted to predict message propagation and the effect of media on an entire population (Berns and Moore 2012; Falk et al. 2012, 2013). However, analysis of processing consistency across individuals suggests that another dimension can be added to the existing literature (Hasson et al. 2004, 2008).

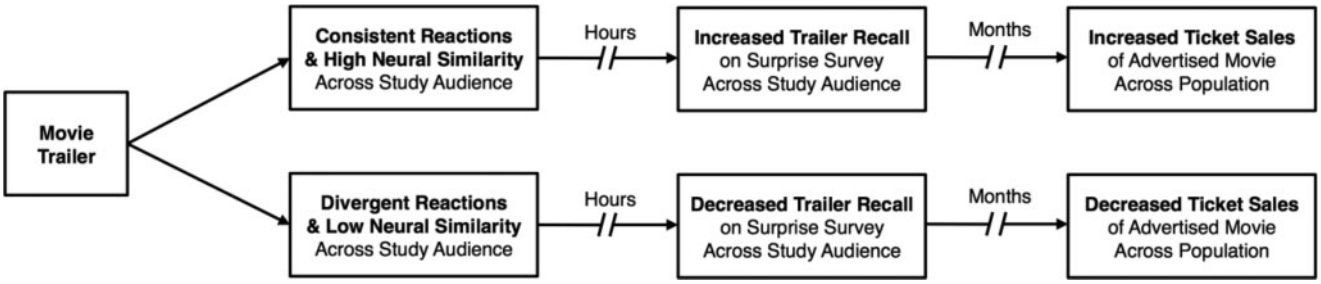
Specifically, Hasson et al. (2008) presented participants with various movie clips while they were undergoing fMRI and computed inter-subject correlations (ISCs) of blood-oxygen-level dependent (BOLD) signals. The researchers found that brain regions associated with the earliest, most primitive stages of sensory processing—primary visual cortex (V1), primary auditory cortex (A1), and an object recognition site in the lateral occipital (LO) lobe—always responded similarly across individuals experiencing the same movie clip. In other words, regardless of the specific qualities and structure of one selected movie clip versus another, each of these regions in one participant behaved similarly to the corresponding region in another participant given the same raw sensory input. These results follow from well-studied neural correlates of early-stage stimulus processing; each sensory modality (e.g., vision, audition, olfaction, gustation) receives input from the external world, transduces this sensory input into a signal, and propagates this signal along stereotyped pathways with ascending complexity of information (Kandel 2000). To illustrate this point, we can examine the processing stages by which one perceives visual input: photons strike photoreceptors in the retina, which is transduced and relayed to the primary visual cortex, followed by pathways and regions that analyze basic features (e.g., edges, color, and size) to identify and recognize simple shapes first and then complex objects. Later stages aggregate information, which achieves further abstraction such as object recognition, semantic interpretation, and combination of multiple objects. Finally, high-level systems are activated engaging contextualization, selective attention, emotional processing, and memory encoding. Progressively more complex information processing is subject less to evolutionarily hard-coded machinery and more to our individual experiences, interpretations, and idiosyncratic response profiles. Therefore, each successive neural processing stage provides a richer experience, but has increasingly many degrees of freedom (i.e., independent stimulus dimensions).

Consequently, higher-order processing often diverges between individuals (e.g., if individuals pay attention to different aspects of the content), but sometimes even this complex processing is shared across an entire audience. Scenes that are universally memorable or jokes that prompt everyone to laugh are moments in which the content seems to transcend our individual brain parameters and speak to many of us in a similar fashion (Meyer 2000). Therefore, stimuli that produce high similarity across more of the brain presumably reflect control of audience interpretations in addition to merely generating similarity in primitive processing. In other words, we can imagine substantially more similar brain activity across individuals viewing identical content in the early stages, with progressively different neural signatures as more personal attributes are incorporated into the stimulus processing. To investigate this concept, Hasson et al. (2008) compared responses to four videos: two movies by acclaimed filmmakers, a documentary-style television show, and unstructured footage of a public park. The percentage of the brain that was statistically similar across individuals for each of the two movies was more than twice that of the television show, which in turn was more than three times that of the unstructured footage. These results suggest that certain qualities of stimuli, perhaps the degree to which they are directed and orderly, drive varying levels of neural synchrony across individuals. In other words, by presenting a coherent and interesting plot, a movie makes individual brains behave more similarly (since interpretations, predictions, etc. are linked to the orderly content) than they do in the absence of any semantic meaning to unify the minds of an audience (e.g., as with unstructured footage).

Hasson et al. (2008) speculate that heightened neural synchrony across individuals during certain stimuli may reflect increased memory processes. The notion that certain visual content is especially memorable has been

**FIGURE 1**

MODEL OF NEURAL AND BEHAVIORAL OUTCOMES OF A MOVIE TRAILER




thoroughly studied (Furman et al. 2007; Olivers, Meijer, and Theeuwes 2006). Other explanations may be found in studies of the interplay between content and attention (Koster et al. 2006), decreases in "mind wandering" (Mason et al. 2007), and effects on shared experiences and sales (Boksem and Smidts 2015; Falk et al. 2012).

Outside of neuroscience, consumer researchers have extensively studied reactions to content, especially advertising. Researchers have found significant effects by increasing content exposure time by repeating messages (Campbell and Keller 2003), using endorsements by popular figures (Choi, Lee, and Kim 2005), appealing to common denominators (Singer and Ashman 2009), presenting testimonials (Albuquerque et al. 2012), and choosing creative media (Dahlén 2005), among other approaches. There are now entire industries that rely on and financially reward the ability to create effective content in an efficient way (Calder, Malthouse, and Schaedel 2009; Sawhney, Verona, and Prandelli 2005). In addition to incentivizing this endeavor, we are exposed to more tools and techniques that offer ways to assess responses to content (Gambetti and Graffigna 2010; Hirschman 1986). Additional studies have sought to measure the level of involvement of the audience (Wang 2006), a sense by which "time flies faster" for certain content (Chaston and Kingstone 2004; Danckert and Allman 2005), and tendencies to prefer one stimulus over another (Lawlor 2009). In marketing, there is a body of work studying satisfaction with advertising content and corresponding measures of future likelihood of consumption (Anderson, Fornell, and Lehman 1994; Sprott, Czeller, and Spangenberg 2009), which is one of the hallmarks of a successful marketing campaign (Bowden 2009; Sashi 2012). However, a formulaic way of modeling probable responses to content is bound by the level of heterogeneity in the population and the difficulty of quantifying many of the aforementioned constructs. Furthermore, existing methods are, at times, inefficient, expensive, or corrupted by subjective biases (Boksem et al. 2015; Swerdlow 1984).

## RATIONALE FOR MOVIE TRAILERS AS CASE STUDY STIMULI

We investigate the similarity between brains in the context of cinematic advertising (i.e., movie trailers). A movie trailer is an especially rich stimulus because it simultaneously tries to tell a story and drive future ticket sales. In other words, movie trailer content is designed to be both narrative and persuasive. To wit, a majority of moviegoers (55.9%) report that trailers influence their ticket purchase decisions more than user reviews, recommendations, or other factors (Barnett, White, and Cerf 2016). In addition to being a medium that generates large sums of money, movies are unusual products in that they attract diverse audiences and offer an experience that benefits from shared involvement. The success of a given trailer depends on faithful transmission of language, symbols, images, sounds, and social nonverbal cues between brains, which implicates neural similarity as a relevant measure. We hypothesize that communication that engages many brains in a similar fashion is more memorable and ultimately leads to increased sales (see figure 1).

Furthermore, despite technology that empowers individuals to experience cinematic content faithfully at home, the experience of shared viewing is key to the medium, as film is a particularly thoughtful form of communication; the medium is social by nature. Directors seek to captivate us, their audience, by carefully orchestrating our reactions, thoughts, and emotions to the presented content. Directors assume that human beings have stereotyped responses to certain stimuli; for example, a movie director trying to instill fear by displaying a spider depends on most human beings having an innate aversion to such an image (Cerf et al. 2015). Similarly, a well-timed gunshot makes us

flinch; a perfect joke triggers universal laughter. Directors spend countless hours trying to tap into the minds of their audiences and identify the commonalities to generate such a carefully calibrated response across multiple individuals (McKee 1999).

Filmmakers' creative efforts have been supplemented by a recent and rapid increase in scholarly attention to predicting the commercial success of movies; researchers have explored potential early indicators of financial outcomes such as a movie's script, expected parental guidance rating, or whether it is a sequel (Eliashberg, Elberse, and Leenders 2006). We contribute a neuroscientific lens to the investigation of these factors by measuring neural synchrony produced by movie trailers with scripts of varying length and semantic complexity, trailers corresponding to different parental guidance ratings, and sequels versus standalone movies. Prior literature has also examined how a film's cast affects its revenue. For example, a star actor tends to be worth $3 million in expected marginal theatrical revenues; however, the per-star economic impact is even higher if the rest of the cast is stronger, which suggests complex interdependencies (Elberse 2007). In this work, we offer practitioners and researchers an additional factor for predicting a movie's box office success that is agnostic about the interdependencies of the aforementioned film characteristics.

## CASE STUDY OF MEASURING CBC TO PREDICT MOVIE TRAILER RECALL AND TICKET SALES

In order to study neural similarity of film consumers in a commercial context, our approach differs from previous investigations into correlated brain activity throughout movies (Furman et al. 2007; Hasson et al. 2004, 2008). Prior studies utilized fMRI, which enabled anatomically precise conclusions especially relevant to the neuroscience community; however, given that fMRI sampling periods are on the order of seconds, these studies do not focus on the temporal dynamics of content communication. Rather, these researchers observed an increased anatomical extent of neural synchrony for structured, memorable content. In addition to assessing content recall, we collect other measures of responses to content that are pertinent to consumer research, including subjective ratings, willingness-to-pay (WTP) scores, and associated sales. We also present examples of computed stimulus characteristics, such as visual and semantic complexity, to test whether they may be antecedents to neural similarity (Barnett et al. 2016). We speculate that simpler movie trailers will be processed more uniformly across participants, thus increasing neural similarity.

We collect our participants' neural data via EEG to achieve substantially higher temporal precision than fMRI; EEG sampling rates are three orders of magnitude higher than fMRI. (Also, from a practitioner's viewpoint, EEG is more practical and accessible for commercial use because the acquisition machinery is portable, substantially less expensive than fMRI, and can be operated more easily.) However, EEG signals (captured at discrete, disjointed electrode sites across the scalp) are much less anatomically precise than fMRI scans (continuous, three-dimensional images), so instead of measuring neural similarity as the anatomical extent of synchrony (i.e., percentage of one brain that is considered similar to another), we compute the overall level of synchrony between entire brains (as an average of activity-correlation values at each of the 32 electrode sites across the scalp; see CBC Computation in Methods; Barnett and Cerf 2016). CBC fluctuates moment to moment, which allows us to address the dynamic interplay of content and neural similarity across individuals. Consequently, we measure the average CBC levels throughout short clips, such as individual movie trailers, and test whether CBC can predict trailer recall and future ticket sales. Thus, we evaluate whether the level of shared neural processing during movie trailers maps to any outcomes with respect to moviegoer preferences and behavior. Lastly, to supplement the neural data, we record other physiological measures, including cardiac data, respiratory data, and electrodermal activity levels. Another important distinction between our work and extant research is that we performed a field study instead of collecting data in a laboratory setting; we invited participants to watch a movie of their choice in a commercial theater while undergoing EEG recording. All participants were asked to choose a movie that they had not previously seen to prevent biased responses due to repeated viewing. For example, imagine two individuals watching a movie together, but only one is seeing the movie for the first time. Both individuals experience the same physical stimulus, but the naïve viewer might feel suspense while the other viewer already knows the upcoming sequence of events. Despite viewing the same content, the two viewers may diverge in stimulus due to differences in their respective prior experiences. We are particularly interested in their responses to the movie trailers, which combine the medium of cinematography with the intent of advertising: to introduce an upcoming product (viz., a new movie) in a memorable way that encourages future consumption (i.e., purchasing tickets when the movie is released in theaters).

We hypothesize that certain trailers will unify content processing across audience members: captivating attention, producing similar emotional responses, generating a memorable experience, and ultimately promoting the decision to buy the advertised product (viz., tickets to the corresponding movie). Conversely, other trailers may be appealing to certain individuals, but will not engender strong parallels across numerous individuals, which in turn will result in diminished memory and future sales of the

advertised movie (see figure 1). To test this hypothesis, we measured synchrony in brain activity across participants viewing movie trailers and determined its predictive power over subsequent recall of the movie trailers in a surprise survey. Furthermore, we test the predictive power of neural similarity over future population-level ticket sales of the advertised movies, and we compare this measure's performance to traditional focus group measures.

## METHODS

### General Procedure

One hundred twenty-two participants watched trailers and movies at a commercial theater that we partnered with for the study (AMC Theaters, Northbrook, Illinois) and responded to a written survey following the viewing; 58 of these participants additionally underwent neural and physiological recordings throughout the trailers and movies (see the appendix for extended procedure, field study timeline, and data overview). Participants were traditional moviegoers who selected a movie of their choice that they had not previously seen from a list of the theater's regular showtimes, and they were given free admission in exchange for participation. Participants were also offered free soft drinks and popcorn, but were not allowed to consume these concessions while undergoing the physiological recordings. For each showtime during which neural and physiological recordings were collected (which we deem a "viewing session") in our study ($n = 44$), we collected data from two participants seated next to each other. All participants were native English speakers with normal hearing who provided informed consent. Additionally, we explained the experiment to other moviegoers and theater staff in the vicinity.

### Neural Data Acquisition

We collected participants' neural data using a 64-channel (32 channels per participant, two participants recorded simultaneously) EEG system (Brain Products GmbH, Gilching, Germany) at a rate of 250 samples per second. Participants were fitted with an EEG electrode cap with a circumference of either 54 or 58 centimeters depending on head size and comfort with the cap's tightness. While the participants were wearing the caps, a washable conductive gel was placed with a syringe at each electrode site on the participants' scalps. We verified that each electrode connection was functioning properly (i.e., capturing electrical activity from the scalp) before starting the recording. In the event that the function of certain electrodes was interrupted or discontinued during the recording, the electrical activity at that site was calculated as a weighted average of signals from nearby functioning electrodes.

### Physiological Data Acquisition

As a series of controls to investigate potential anomalies in the neural data, a number of additional physiological data were collected: (1) participants' cardiac data, using a three-lead electrocardiography (ECG) system (BIOPAC Systems, Goleta, California) via electrode stickers placed on the lower-left abdomen, upper-left chest, and upper-right chest (forming a large triangle around the heart) that were clipped to wires and connected to a transmitter; (2) participants' respiratory data, using a respiration belt transducer (BIOPAC Systems) placed around the chest to measure its extent of expansion; (3) participants' galvanic skin response (GSR) using an electrodermal activity sensor (BIOPAC Systems) via electrode stickers placed on the index finger and middle finger of the participant's nondominant hand; (4) high-definition videos of participants, using a Canon C300 "Red" Cinema EOS Camcorder (Canon Inc., Tokyo, Japan) with a Canon 70-200mm f2.8 lens to account for the low lighting during the movies, which captures eye movement and location along with facial expressions.

### Free Recall and Survey Data

Immediately following the movie, participants were asked to respond to a surprise survey. The element of surprise was required to prevent them from making an unusual effort to remember the content or prepare their answers in advance. Participants continued to be monitored by the aforementioned equipment while they completed the survey. We allowed participants to spend as much or little time as they wished answering the questions.

First, participants were asked to recount the plot of the movie in detail. Second, they were asked to write the title and plot for each trailer that they remembered. For each of these trailers, they were asked about their WTP to watch the full movie upon release ($0–$30) and to what extent they enjoyed the trailer (on a 1–10 scale, 1 = "not at all," 10 = "very much"). Participants were also asked questions about their general movie preferences; for example, participants were provided a list of four genres (Comedy, Action, Horror, Drama) and asked to rank them (on a 1–4 scale, 1 = "most preferred," 4 = "least preferred"). Lastly, participants were asked to optionally list their gender and age.

Six months later, we conducted an additional surprise survey. We received responses from 36 of the original 58 participants (62%). The survey primarily repeated a subset of the previous questions (e.g., participants were asked to list titles of any trailer they remembered seeing during the study), which enabled us to compare trailer recall immediately after viewing with recall of those trailers six months later. No stimuli were provided to assist participants in recalling the trailers they had seen during the study.

## CBC Computation

We computed CBC as moment-to-moment synchrony in EEG data across participants experiencing the same audiovisual stimuli. Our comparisons across individuals are computationally akin to measures of neural synchrony across different regions within a single brain, which have been thoroughly analyzed with the aim of understanding neural disorders such as epilepsy. In these disorders, abnormal patterns of synchronization within an individual's brain underlie seizures (Cerf and Barnett 2014).

To effectively compare the activity of a given pair of brains, we collected information from diverse brain regions; the 32 EEG electrode sites were distributed across the entire scalp according to the actiCAP 64Ch Standard-2 (green holders) montage (Brain Products GmbH, Gilching, Germany; see appendix figure 4). However, the electrode site montage can be optimized for specific stimuli and predictions, and our method can still offer predictive power even if fewer electrodes are used (see appendix tables 1 and 2), which may help practitioners minimize EEG system costs, decrease experimental setup and calibration time, and increase participant comfort.

At each electrode site, we measured neural activity over time as the power (dB) of alpha oscillations (also known as Berger's wave; Berger 1929) in the recorded EEG data, which are commonly associated with attention to visual stimuli (Dmochowski et al. 2014; Klimesch 2012). To do this, we performed a Short-Time Fourier Transform (STFT) of the raw EEG signal at each timestep, filtered the resulting Power Spectral Density (PSD) matrix, and multiplied the common logarithm (base 10) of the PSD matrix by 10; we then assembled a time series of activity for that participant at the given electrode site. To control for the effects of trailer order and grouping, time of day, idiosyncratic content preferences, and other potential influences, participants were exposed to varied sequences of movie trailers (see Stimuli). In our analysis of a given movie trailer, we matched the data of every participant that viewed this trailer (regardless of viewing session) and compared the corresponding neural activity of every pairwise combination of these participants. For example, if participants A and B watched a particular trailer, and participants C and D watched the same trailer at a different time, we computed neural similarity for all six (4 choose 2) possible combinations of these participants: AB, AC, AD, BC, BD, CD. Since our data includes 58 participants, we have a maximum of 1,653 (58 choose 2) unique pairs of such neural comparisons. For a given pair of participants and a given electrode site, we computed the Pearson correlation for each timestep. Next, we averaged this time series of correlations at a given site with the corresponding time series of each pair of participants who viewed the same trailer. Finally, we averaged across the 32 electrode sites to arrive at a single value of neural similarity at each timestep, thus producing the CBC time series. Additionally, as a control for eye blinks and muscle movements, which primarily affected the two frontal polar electrode sites on the forehead (Fp1 and Fp2; see appendix figure 4), we repeated our CBC computations without those channels and found that these differences were negligible with respect to all of our findings. The CBC values without Fp1 and Fp2 were typically 2.77% ± .92% (mean ± standard deviation) higher than the CBC values with all 32 electrode sites.

## Data Processing

Due to the large quantity of data—approximately 10 terabytes in aggregate—we stored and redundantly archived the data on 4 terabyte, high-performance external hard drives (G-Technology, San Mateo, California), which feature fast streaming interfaces (e.g., USB 3.0) in order to process video images in a timeline-based video editing software, Adobe Premiere Pro (Adobe Systems Inc., San Jose, California) and analyzed physiological data in MATLAB (MathWorks, Natick, Massachusetts). We used EEGLAB (Swart Center for Computational Neuroscience, University of California, San Diego), a MATLAB freeware toolbox, to import and process the raw neural data files. Similarly, we used AcqKnowledge (BIOPAC Systems) to convert the physiological data into a MATLAB-compatible format.

## Stimuli

Across all viewing sessions ($n = 44$), participants viewed 5.84 ± 1.26 trailers before their selected movie. Participants' movie selections corresponded with 13 trailers presented more than once and subsequently recalled by more than one participant. These trailers represented movies that ultimately earned over $3.58 billion in worldwide theatrical revenue. Trailers were consistent in length (136 ± 20 seconds), but diverse along other dimensions. Specifically, numerous studios were represented in this sample: four trailers were distributed by Fox, two by Warner Bros., two by Sony Pictures, two by Focus Features, and three by other studios. Furthermore, these trailers corresponded to feature films rated G (one), PG (four), PG-13 (five), and R (three) by the Motion Picture Association of America (MPAA). Additionally, six of these trailers belonged to an established media franchise either as a direct sequel (*22 Jump Street*, *How to Train Your Dragon 2*, and *The Amazing Spider-Man 2*) or by sharing an existing fictional universe (*Muppets Most Wanted*, *Mr. Peabody and Sherman*, *X-Men: Days of Future Past*); the other seven trailers corresponded with stand-alone films.

# RESULTS

## Subjective Measures

*Participants' Free Recall, Ratings, and WTP.* A particular movie trailer was freely recalled by 34.45% ± 13.24% of participants undergoing neural and physiological recordings ($n = 58$) in surprise surveys after their movie of choice (i.e., approximately two hours after viewing the movie trailers). Participants tended to rate their enjoyment of recalled trailers at 6.50 ± .94 (10-point scale; see Methods), which suggests moderate enjoyment. WTP for a particular movie, based on the corresponding recalled trailer, was \$8.24 ± \$1.97. Participants undergoing these recordings recalled slightly fewer trailers (1.98 ± 1.30; $n = 58$) than those who only responded to the survey (2.60 ± 1.50; $n = 64$), but this difference was not significant (unpaired two-sample *t*-test).

*Initial Recall Predicts Recall Six Months Later.* Our model of responses to movie trailers (figure 1) suggests that increased trailer recall (surveyed immediately after the movie) leads to increased ticket sales of the corresponding movie upon its release months later. The model assumes that increased trailer recall persists to a certain degree in the interim (months) between the advertisement and the purchasing opportunity (i.e., movie release). We verified this assumption by conducting an additional surprise survey ($n = 36$; see Methods) six months after the participants responded to the study. In aggregate, trailer recall fell by an additional 59% from the initial survey to the additional survey six months later. However, memory appeared to decay in a uniform manner: initial counts of trailer recall were highly correlated with recall counts of the same trailers six months later (Pearson's correlation $r = .87$, $p < .01$; Spearman's rank correlation $\rho = .75$, $p < .01$).

## Neural Measures

*Participants' Neural Similarity.* CBC was first normalized (to range from zero to one) across all trailers. We averaged the normalized CBC throughout each movie trailer; these averages ranged from .45 (*Mr. Peabody and Sherman*) to .55 (*X-Men: Days of Future Past*). Even though trailers varied in length (i.e., exposure time), we found no relationship between CBC and length ($r = .07$, $p = .82$). In general, the MPAA parental guidance ratings were uncorrelated with CBC ($r = .01$, $p = .97$), but four of the six trailers with the highest CBC were rated PG-13 (i.e., "Some material may be inappropriate for children under 13"). The order in which a trailer was presented exhibited a weakly negative correlation with CBC ($r = -.33$, $p = .28$); in other words, trailers shown earlier generated slightly more neural similarity, on average, than later trailers.

*Neural Similarity Predicts Movie Trailer Recall.* The average CBC throughout a movie trailer was highly correlated with the proportion of participants ($n = 122$) who freely recalled that trailer ($r = .66$, $p = .01$; figure 2). Furthermore, no significant correlation existed between free recall and two measures of audience preferences: subjective rating ($r = .24$, $p = .43$) and WTP ($r = –.13$, $p = .67$). Taken together, these results suggest that neural similarity may complement self-report measures as an additional predictor of free recall.

*Neural Similarity Predicts Movie Sales.* Box office performance data collected from the Internet Movie Database (IMDb.com) was measured as the total revenue generated by a particular feature film (on average for our sample: \$275 ± \$266 million). Since each movie was in release for a different length of time (25 ± 10 weeks) depending on numerous factors (other movies in release, time of year, distribution agreements between studios and theaters, etc.), we computed the average weekly ticket sales to reflect box office performance of each film normalized by its availability to consumers. (There may be other ways to control for the "supply" of a movie—for example, normalizing by the number of theaters distributing a film. However, the available databases do not control for the number of screens showing each movie per theater).

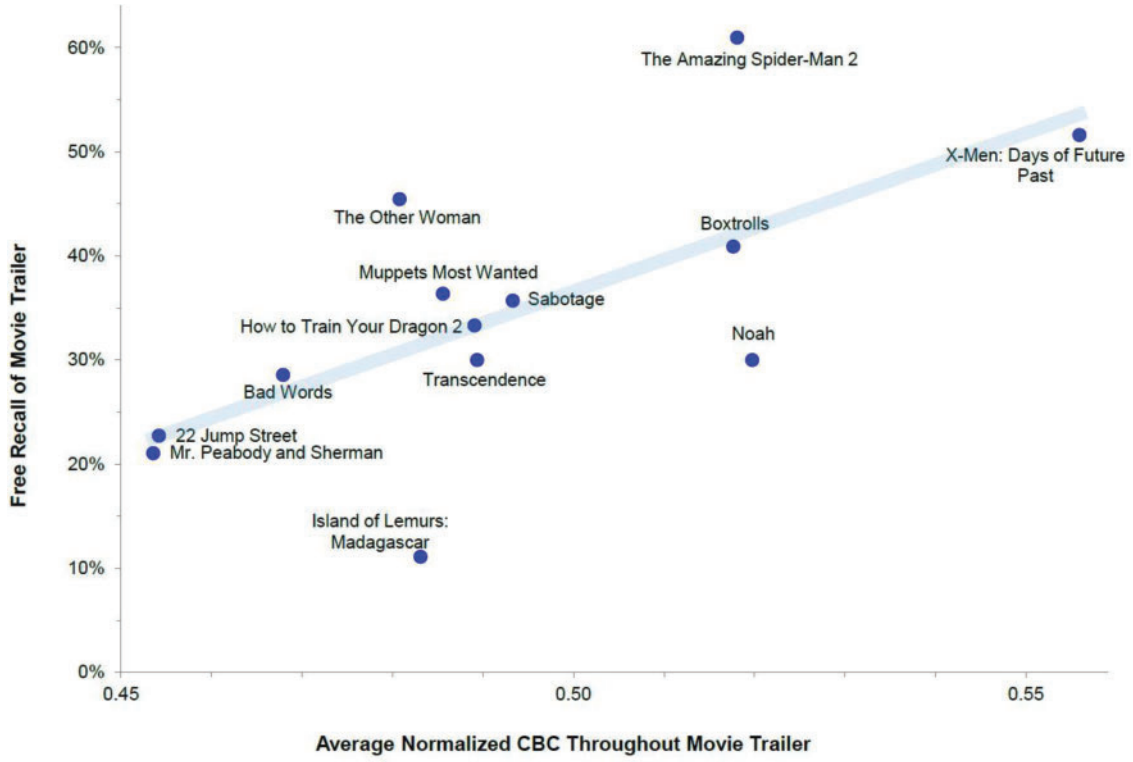
Average CBC throughout each movie trailer was a strong predictor of average weekly ticket sales of the advertised film ($r = .68$, $p = .01$; figure 3). Additionally, even without normalization by weeks in release, CBC was positively correlated (albeit less strongly) with opening weekend revenue ($r = .51$, $p = .08$) and with total lifetime theatrical revenue ($r = .52$, $p = .07$).

Free recall of trailers was also positively correlated with weekly ticket sales ($r = .56$, $p = .04$), albeit less strongly than the CBC-sales link (see figure 4). Both CBC and free recall were better predictors of future sales than our subjective report measures of recalled trailers (ratings-sales: $r = .43$, $p = .14$; WTP-sales: $r = .02$, $p = .96$).

*Temporal Dynamics of CBC Predictions.* We repeated the aforementioned analysis of CBC's predictive power over trailer recall and corresponding future sales, but rather than averaging CBC throughout each trailer, we performed more temporally precise computations. Specifically, we computed the 5-second leading CBC for every second (i.e., the first data point of a given trailer represents the CBC for 0–5 seconds of the stimulus, the second data point represents 1–6 seconds, etc.). Next, we calculated the moment-to-moment (rather than averaging throughout the full length of each trailer) CBC-recall and CBC-sales correlations to examine the temporal dynamics of CBC predictions (see figure 5). Both the CBC-recall and CBC-sales relationships were particularly significant ($r > .60$, $p <$

**FIGURE 2**

NEURAL SIMILARITY PREDICTS FREE RECALL OF MOVIE TRAILERS




.02) 16–21 seconds after stimulus onset. While each trailer has its own style and structure, the first semantic content is delivered around this time; in our sample, the first sentence tended to complete by 15 ± 5 seconds into the trailer. The observed importance of these early moments aligns with prior studies on first impressions (Willis and Todorov 2006; Olivola and Todorov 2010; Rule et al. 2011).

## Information Theory Measures

One may ask whether neural similarity is driven by collective understanding or collective confusion. For example, one can imagine that unclear or incoherent content will puzzle viewers, and in doing so, incite effortful processing that could drive similar brain activity. To show that this is not the case, we test the visual and semantic complexity of the content. Our proposed model (figure 1) suggests that certain stimuli drive greater levels of synchrony across individual brains than other stimuli. We have shown that CBC can identify stimuli (viz., movie trailers) that are more likely to be recalled and that are correlated with population-level sales of the corresponding advertised films. From an information theory perspective, we reason that stimulus complexity should be antagonistic to driving similarity in stimulus processing across individuals. Conversely, less complex stimuli will provide fewer degrees of freedom for stimulus processing, which would then increase similarity throughout an audience. However, these results do not suggest that an infinitely simple stimulus (e.g., a blank screen, no words) would drive uniform processing and increase neural similarity; we expect that some minimum content threshold must be met to capture attention.

*Visual Complexity Decreases Neural Similarity.* For each frame (24 per second) of the 13 movie trailers, we measured the entropy (i.e., statistical randomness) of the intensity image. For a uniformly intense image (meaning every pixel has equal brightness), entropy is zero; conversely, an image of random pixel intensities (e.g., the "snow" displayed on analog televisions when no signal is received) is maximally entropic. Next, we computed the average entropy across all frames for each trailer, which corresponds to its overall level of visual complexity (i.e., disorder). More visually complex movie trailers resulted in lower neural similarity across participants;

**FIGURE 3**

NEURAL SIMILARITY PREDICTS MOVIE TICKET SALES

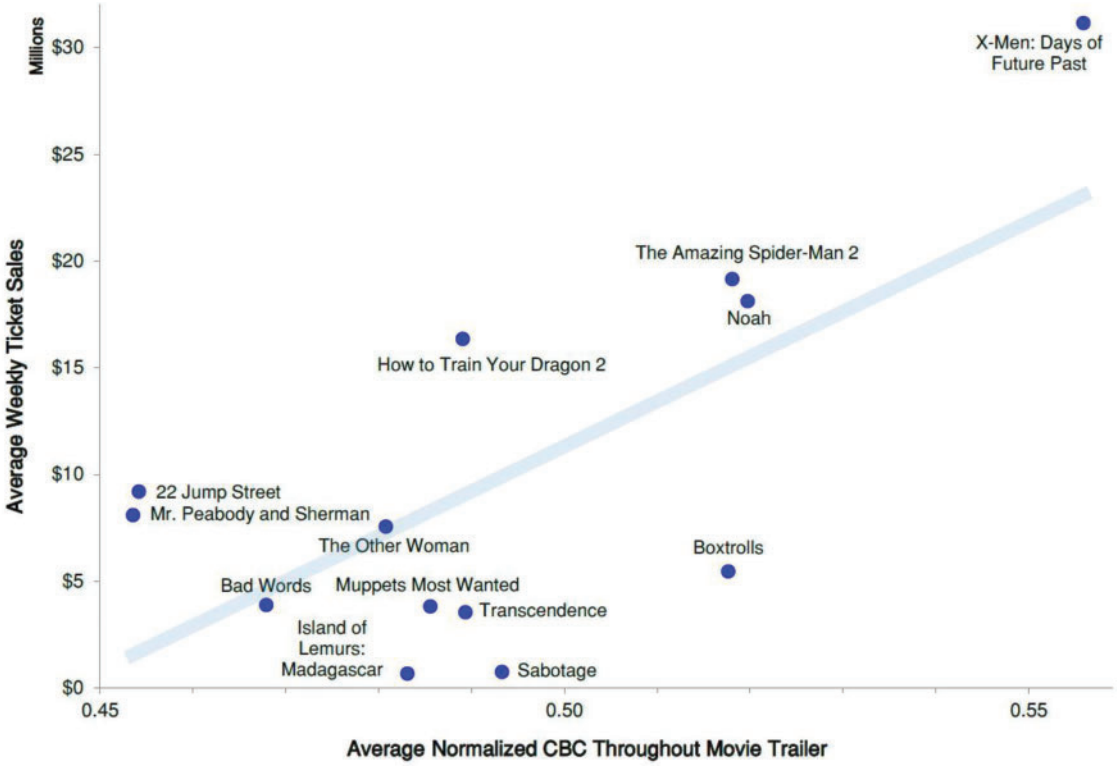
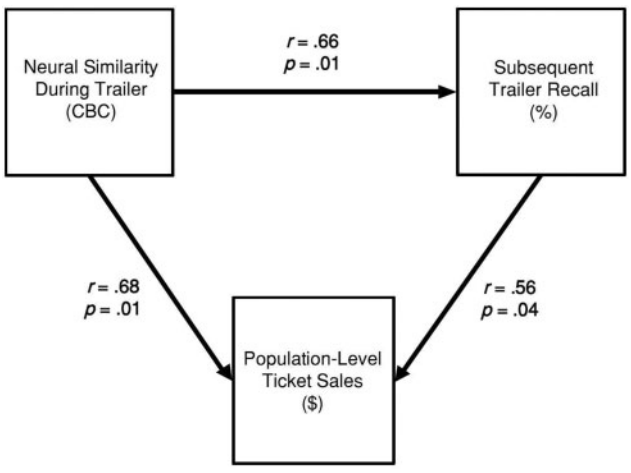



**FIGURE 4**

CORRELATIONS AMONG NEURAL SIMILARITY, FREE RECALL, AND MOVIE TICKET SALES



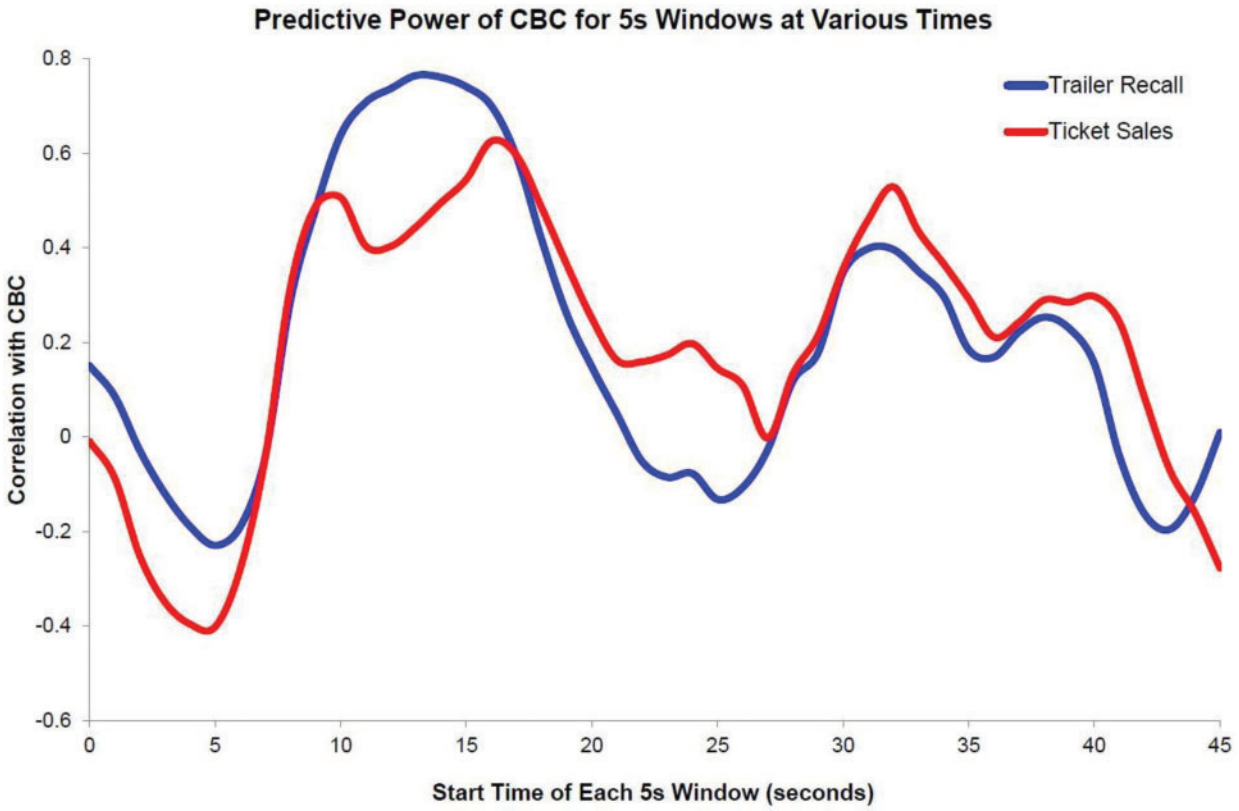

average entropy had a strong, negative correlation with CBC ($r = –.71$, $p < .01$; see black line in figure 6).

*Semantic Complexity Decreases Neural Similarity.* To quantify the information contained in each movie trailer in an alternative way, we transcribed all spoken words (narration and character dialogue) and counted both the total number of words and the number of unique words contained therein. Consonant with the visual complexity results, CBC decreased as measures of semantic complexity increased (see figure 6, left panel). Conversely, simpler messages (i.e., fewer total and unique words) tended to produce higher neural similarity across participants. In particular, the total number of words in a given movie trailer was negatively correlated with CBC ($r = –.68$, $p < .01$; see green line in figure 6) and the number of unique words had an even stronger negative correlation with CBC ($r = –.73$, $p < .01$; see blue line in figure 6).

Taken together, movie trailers that drive neural similarity appear to be efficient in information transfer. In other words, low information complexity (both visual and semantic) may enable otherwise similar content to transcend individual differences across an audience. This finding is

**FIGURE 5**

PREDICTIVE POWER OF MOMENT-TO-MOMENT NEURAL SIMILARITY




consistent with extant marketing literature suggesting that, all else being equal, simpler advertisements have greater impact on consumers (Barnett et al. 2016).

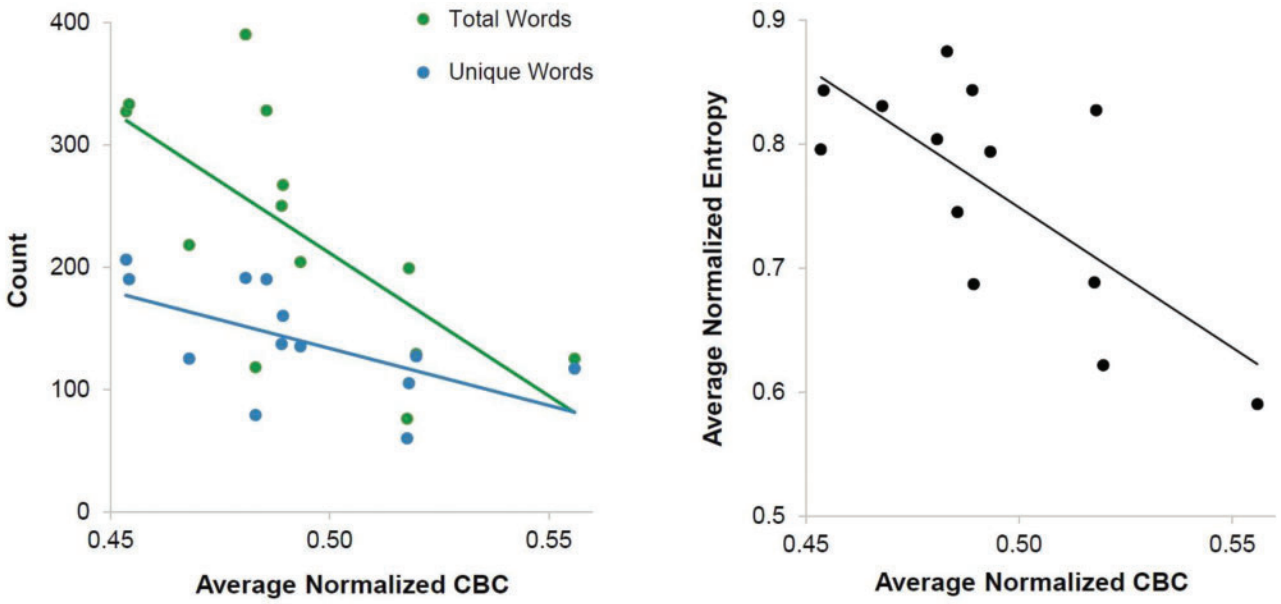
## Other Physiological Measures

Hypothetically, neural similarity could be driven by congruence in other physiological processes, such as arousal. For example, brain activity may be more similar across people who have elevated cardiac or respiratory rates. To investigate whether neural similarity is related to basic biological processes and to control for alternative explanations for similarity across individuals, we collected cardiac, respiratory, and electrodermal activity levels in addition to the neural measures. Qualitatively, the participants appeared relaxed and remained seated throughout the procedure. Participants' physiological data was within normal resting ranges: average heart rate was 65.39 $\pm$ 3.52 beats per minute (bpm) and average respiratory rate was 14.98 $\pm$ .49 breaths per minute. We measured electrodermal activity (EDA) as the within-participant relative level (%) of skin conductance (microsiemens) during a given trailer compared to baseline levels collected before the first trailer was presented. For a given participant and trailer, EDA tended to be 29.56% $\pm$ 45.94% higher than the participant's baseline levels. In addition to analyzing the average levels of these physiological data, we also computed correlation levels across participants (analogous to our computation of CBC; see Methods). However, none of these measures were strongly predictive of subsequent trailer recall or ticket sales ($|r| < .50$, $p > .10$; see appendix table 3 for the specific correlation values for each relationship).

Taken together, these results suggest that neural similarity and its predictiveness over both trailer recall and ticket sales reflect the mental experience of content rather than more primitive physiological processes. Unlike other organs whose functions are ephemeral, the brain continues to represent, transform, interpret, and recall content even after it is no longer present. Thus, measuring the brain's activity is fundamental and uniquely important to assessing responses to content.

**FIGURE 6**

INFORMATION COMPLEXITY DECREASES NEURAL SIMILARITY




## DISCUSSION

The results from our case study suggest that movie trailers that ultimately command elevated levels of recall and ticket sales (see model in figure 1) were able to drive similarity in neural processing among participants experiencing the same stimuli. In other words, these movie trailers transcend idiosyncratic preferences to achieve a pervasive impact throughout the audience. These findings are consistent with other neuroscience studies of content effectiveness. For example, when a story is told well, its content connects to many brains, making them respond similarly (Hasson et al. 2008). Conversely, a boring story makes our brains drift in different directions, effectively rendering dissimilarity in the neural response profile (Mason et al. 2007).

Specifically, our method revealed significant linear relationships between CBC and free recall of movie trailers (see figure 2; $r = .66$, $p = .01$) as well as weekly population-level ticket sales (see figure 3; $r = .68$, $p = .01$). In the case study's sample of advertised movies, both CBC and free recall are stronger correlates of future sales than our measures of subjective rating and WTP. However, throughout the months from the launch of movie trailers to the eventual release of the corresponding films, numerous additional factors are introduced to the population of prospective moviegoers that could bias purchase decisions (e.g., alternate choices of movies, critical reviews, media coverage, other advertisements). Despite the potential interference between trailer presentation and movie release, our preliminary evidence suggests that if content drives neural synchrony originally (i.e., during the movie trailer), individuals will remember the content (see figure 2) and their initial preferences will be reflected in eventual movie sales (see figure 3). Indeed, our additional surprise survey showed that initial recall predicts recall six months later, both in terms of quantity (Pearson's $r = .87$, $p < .01$) and rank (Spearman's $\rho = .75$, $p < .01$).

Neural similarity can complement subjective measures of audience experience. For example, focus groups typically rely on self-reports (e.g., free recall, ratings of enjoyment, WTP), which have been generally effective in the past (Campbell and Keller 2003; Cox, Higginbotham, and Burton 1976). However, subjective reports can be biased by countless factors, including unrelated preferences (Gummesson 2005), mood (Thomas and Diener 1990), hunger (Green et al. 1994), or external influences such as room temperature (Palinkas 2001), and even levels of ambient lighting (Hoffman et al. 2008). Moreover, the artificial interactions of focus group studies are sometimes criticized for interrupting the audience, thereby removing the participants from the experience in order for them to evaluate it. By contrast, a passive measure permits the audience to remain immersed in the experience without the need for interruption or effortful reflection. As a result, passive measures may lead to a more accurate understanding of the

true effects. Additionally, we are able to make temporally precise observations (see figure 5) by collecting data continuously rather than at discrete points in time, as is the case with focus group studies. Accordingly, we observed that early moments of a movie trailer were the most impactful, which lends support to the idiom "first impressions are the most lasting." While focus group data may suggest this concept broadly, our moment-to-moment data provides the requisite evidence to make stronger conclusions and corroborate prior studies (Olivola and Todorov 2010; Rule et al. 2011; Einhäuser et al. 2009; Willis and Todorov 2006). Therefore, our proposed methodology may alleviate certain situations in which asking participants for opinions and self-assessments is impractical or distracting. By contrast, a neural measure does not involve active responses by participants, so the method is inherently less susceptible to conscious reporting biases. Furthermore, a neural measure may also capture subconscious reactions and preferences that are inaccessible through conventional techniques (Mackay, Cerf, and Koch 2012), which ultimately should strengthen predictions over relevant consumer decisions (e.g., product purchases; Falk et al. 2012), especially when used in concert with direct survey questions asked at times that do not interrupt the experience. Our methodology removes the biases of active, conscious reporting, and hypothetically measures some aspect of subconscious experience, which may explain why our case study suggested that CBC was a better predictor of box office performance than free recall, ratings, or WTP. Our work contributes a technique, use case, and empirical support to the burgeoning interdisciplinary field of neuromarketing, because brain data provided additional insight into consumers' minds and behavior than traditional data alone.

Additional subtleties may not be apparent in studies of an individual brain's response profile, but are revealed in our analysis of the collective neural similarity measured across a group of people. For instance, prior work performed segmentation according to neural similarity among subgroups of a film audience (e.g., segmentation by gender, age, genre preferences) and uncovered meaningful between-group differences in moment-to-moment neural responses (Barnett and Cerf 2015). While the exact phenomena underlying elevated neural similarity have yet to be discovered, neuroscientists have shown that viewers' brains behave similarly while experiencing certain content. For example, extensive literature has focused on "mirror neuron," which are clusters of neurons that are active when humans and animals engage in specific actions or observe similar actions performed by others (Gallese et al. 1996). More recently, these mirror neurons have been implicated in our understanding of empathetic responses to a variety of stimuli including film (Konigsberg 2007). In addition to content relatability, information theory suggests that message clarity also underlies processing similarity. Supporting this concept, previous studies have shown that unstructured or incompletely narrated video clips yield lower neural similarity than when there is a single focal point and content is not open to personal interpretations (Hasson et al. 2008). While these findings indicate the existence of a lower bound of information necessary to drive neural similarity, this work and others (Barnett et al. 2016) suggest that there is also an upper bound (see figure 6). We found that elevated semantic complexity of movie trailers predicts decreased neural similarity; CBC was negatively correlated ($r < -.68$) with the number of total words, number of unique words, and visual information complexity (measured as the entropy of the intensity image of each frame of the video). Taken together, these results support minimalistic design principles (cf. the US Navy's "keep it simple, stupid" principle) and suggest that information clarity is important across processing modalities (i.e., semantic processing and visual processing). These neuroscience findings fit with existing thoughts and literature regarding film that suggest that the extent of narrated guidance is a "shared social resource" that enables an audience to make hypotheses throughout a story (Bordwell 1985; Murtagh, Ganz, and McKee 2009; Plantinga 2007). The notions that an audience can be guided to process information in a certain way throughout a film and that effective movies have more control over the minds of an audience have been discussed since the early days of filmmaking and are supported by a variety of interviews with filmmakers (Eisenstein 1925).

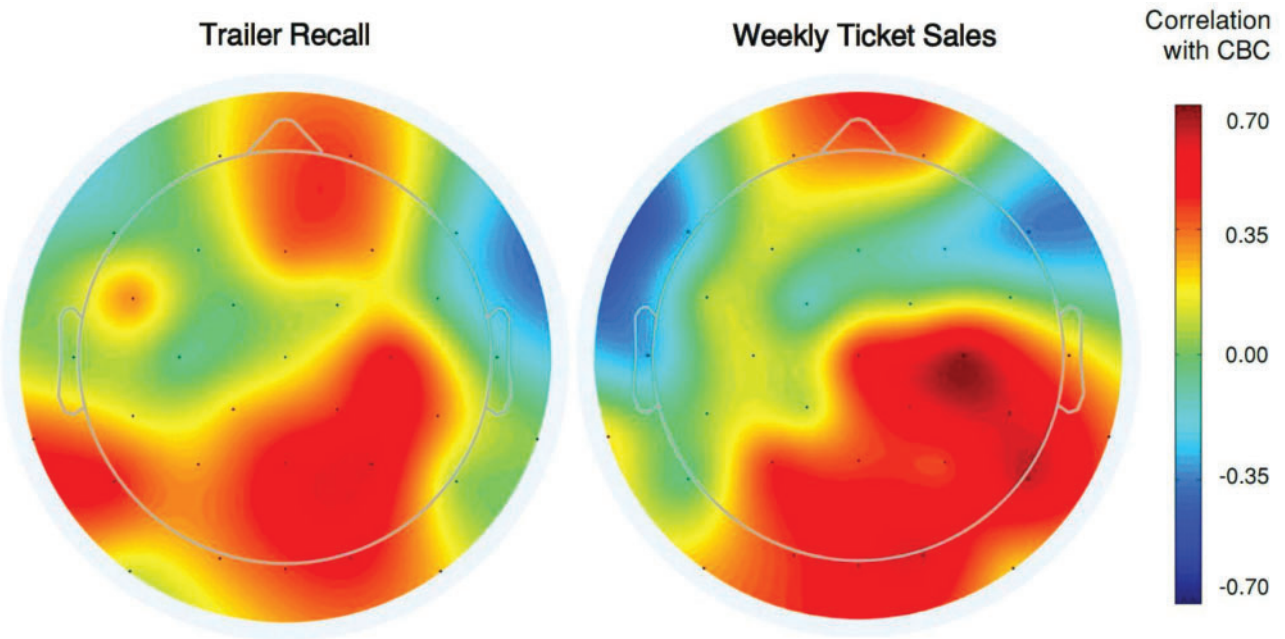
## Limitations

This work was intended to demonstrate that our method of measuring neural similarity could serve as an additional predictor of consumer responses to advertisements (specifically, movie trailer recall and related sales). Neural similarity should be viewed as a relative measure for comparable stimuli as opposed to an absolute measure by which an arbitrary stimulus can be judged; the CBC for people viewing a painting should not necessarily be compared to an audience listening to music. Additionally, by no means do we suggest that our measure is optimal; in fact, averaging across all 32 electrodes is certainly suboptimal, since some brain regions are more involved in sensory processing (e.g., posterior electrodes capture visual processing signals; see figure 7 and more predictive electrode montages in appendix tables 1 and 2). However, in general, the number of recording channels is highly correlated ($> .9$) with average correlations between CBC and each of the dependent variables in our case study. Therefore, we chose to use all 32 electrodes rather than presenting a montage that was specifically optimized for our use case, which reduces the possibility of overfitting to a limited set of data.

Furthermore, our comparisons between CBC and subjective responses are limited to the two metrics that we derived from the surveys of recalled trailers: enjoyment

**FIGURE 7**

CBC PREDICTIVE POWER VARIES BY BRAIN REGION




and WTP. There are many other survey questions that could assess subjective feedback in different and potentially better ways. Our survey questions sought to measure attitudes about the remembered content, whereas alternatives could be tailored to assess intentions, which are likely to be more predictive of behavior (Ajzen and Madden 1986).

Another major class of limitations to this study is due to the rather specific style and format of movie trailers. While neural similarity proved to be highly correlated with numerous metrics (e.g., free recall, future sales, image entropy, semantic complexity) associated with the 13 movie trailers in our case study sample, we have yet to test whether its predictive power holds with a larger sample of stimuli. Also, our limited number of movie trailers may have amplified our observed effect sizes and increased the possibility of Type I and Type II errors. Neural similarity may be less predictive for dissimilar stimuli that rely on different sensory modalities, processing effort, length of time, prior knowledge, contextual understanding, and other experiential parameters (e.g., written text, audio messages, songs, sporting events, political debates) and may be less effective in comparing less homogenous collections of stimuli. Nonetheless, our initial analysis of responses to other stimuli has been promising. For example, in parallel work, neural similarity among participants viewing an advertisement for Coca-Cola, which was only 30 seconds long (compared to the average movie trailer length of 136 seconds), is predictive of consumer responses on a moment-to-moment basis (Barnett and Cerf 2015). However, this work focused on audiovisual advertisements that seek to persuade audience members and earn favorable judgments. Indeed, our data shows that average subjective ratings for trailers ranged from neutral (4.50) to positive (7.47) on our 10-point scale (see Methods), so our study does not account for strongly aversive stimuli. An implicit assumption in our model (figure 1) is that unified responses also have positive valence, but we can imagine a situation in which observers universally dislike content and therefore would also yield high neural similarity despite the expectation of adverse consumer responses. Thus, our conclusion is a conservative one: at most, neural similarity is a necessary, but not sufficient, condition to predict enhanced consumer outcomes (e.g., memory, sales) for an arbitrary type and selection of content (Calder and Malthouse 2008).

## Future Directions

Since our goal in this work is to demonstrate how neural similarity can be utilized as a practical and powerful predictor of the behavior of film consumers, we have left refinements of our method for future study. Such refinements

include focusing on specific brain regions and other EEG frequency spectra, which could yield additional answers concerning the neural mechanisms driving between-individual synchrony, which is a focus of the neuroscience community. On the computational side, additional filters and transformations could be tested to optimize the speed and accuracy of the readings. Furthermore, we could extend our analysis to include eye tracking (Teixeira et al. 2010), facial responses, and other measurable behavioral responses to potentially improve the predictive power of our measures even above the current high levels. Additionally, the usage of other neural measurement technology (such as intracranial recordings) could prove to be enlightening, especially in the search for regions or cells in the brain that are particularly associated with stimulus processing (Cerf et al. 2015).

Outside of marketing and cinematic applications, this model could prove to be a powerful tool to generating more effective content. Be it in education, gaming, music, politics, product design, or any other field in which content is being delivered to an audience, communicators rely on the consistency with which multiple individuals process the same stimulus. Accordingly, future work should seek to quantify moment-to-moment processing consistency across individuals experiencing different types of stimuli.

Further, this technique might offer an alternative way to identify and diagnose communication and attention disorders (Belmonte 2000; Townsend, Courchesne, and Singer 1996). Neuroscientists have already shown that the extent to which viewers can recognize emotion in film can predict autism spectrum conditions (Golan and Baron-Cohen 2006; Klin et al. 2002), and recent clinical works support the belief that detecting persistent asynchrony in moment-to-moment CBC data might also predict levels of autism.

## Conclusion

A single brain can reveal so much about a person, but the study of multiple brains can add another dimension to our understanding. Our case study suggests that advertisements that generate elevated neural similarity across participants also are more memorable (indicated by increased free recall; see figure 2) and persuasive (indicated by increased sales; see figures 3 and 4). Interestingly, neural similarity was more predictive of population-level sales than participants' recall or ratings, possibly because the passively acquired neural data was less susceptible to the biases of active, conscious reporting. Furthermore, we performed our study in the field (viz., in a commercial movie theater) in order to demonstrate viability for practitioners; we also chose a relatively inexpensive neural acquisition method (EEG) so that our technique could be widely accessible.

While the specific biological mechanisms underlying changing levels of neural synchrony have yet to be elucidated, we hypothesize that systems corresponding to attention, memory, emotion, and choice are being activated by certain content, producing measurable neural similarity during stimulus processing and subsequent content recall and related purchase decisions. It has not escaped our notice that increased synchrony during certain stimuli may reflect relative preference, consensus, agreement with persuasive arguments, content comprehensibility, or simply engagement. In particular, we found that neural similarity was linked to content clarity along several dimensions (specifically measured as semantic or visual simplicity; see figure 6), lending support for minimalistic design principles. Overall, since communication in any form inherently depends on interactions between people, comparing neural activity across individuals fits as a lens to view this complex area of research. Beyond even the applications for connecting with consumers more effectively, further study of simultaneous brain activity could lead to a new frontier in human communication and empathy.

## DATA COLLECTION INFORMATION

The first author collected the EEG data, other physiological data, survey data, and free recall data from a field study in 2014 (commercial movie theater, AMC Entertainment Inc., Northbrook, Illinois). The first author and second author analyzed these data jointly.

# APPENDIX

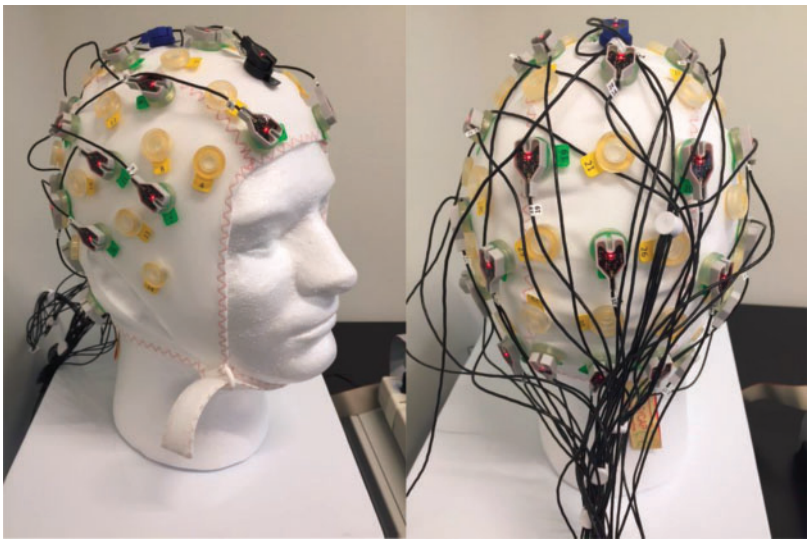
## EXTENDED PROCEDURE

Each viewing session consisted of the following steps:

1. Qualified prospective participants included native English speakers with basic literacy skills (capable of reading and completing an introductory survey). These individuals were offered to take part in the study in exchange for free admission to a movie of their choice that they had not previously watched. Participants provided informed consent, which emphasized that the EEG technique requires the use of sticky, visible saline gel in their hair.
2. Before participants were seated, EEG caps needed to be prepared for the study. The experimenters had access to multiple cap sizes for different head diameters (54 or 58 centimeters) and the appropriate cap was selected for each participant. The electrodes were snapped into the correct holders according to a specific scalp location map (called a montage). It was helpful to label each electrode with a number and label the corresponding number to the appropriate plastic holder on the EEG cap. Also, it was easier to attach the electrodes to the plastic holders if the cap was placed on a foam model head (see appendix figure 1, left panel).
3. Two participants (not necessarily affiliated with each other) who chose the same movie were seated next to each other in the theater auditorium 30–40 minutes prior to the theater's listed showtime for the chosen movie. Typically, successive showings in a particular auditorium had only a 30–40 minute interim between the previous movie's conclusion and the subsequent showtime; therefore, participants were seated immediately after moviegoers had exited the auditorium following the previous movie. An equipment cart was situated near the participants (preferably behind them, but alternatively located laterally to either participant).
4. An EEG cap (which resembles a cloth swim cap with round, plastic holders for EEG electrodes) was placed on each participant's head with the participant's assistance. The experimenter ensured that the cap fit the participant closely and was worn symmetrically so that the location of a particular electrode on one participant corresponded to the same anatomical location on another participant. A fabric fastener below the participant's chin was closed so that the cap did not move, but was not uncomfortably tight. Additionally, to maximize each participant's comfort, the experimenters angled the thin cables extending from each electrode away from the participant's face by rotating the electrodes in place in their holders (i.e., forming a "ponytail" of cables behind head; see appendix figure 1, right panel).
5. The EEG electrode cables converged to a ribbon, which connected to a control box (see appendix figure 2, left side of image). The impedance button, denoted *Z*, was pressed to activate an LED in each electrode. If there was high impedance, the

**APPENDIX FIGURE 1**

PREPARING AN EEG CAP



**APPENDIX FIGURE 2**

EEG SYSTEM COMPONENTS

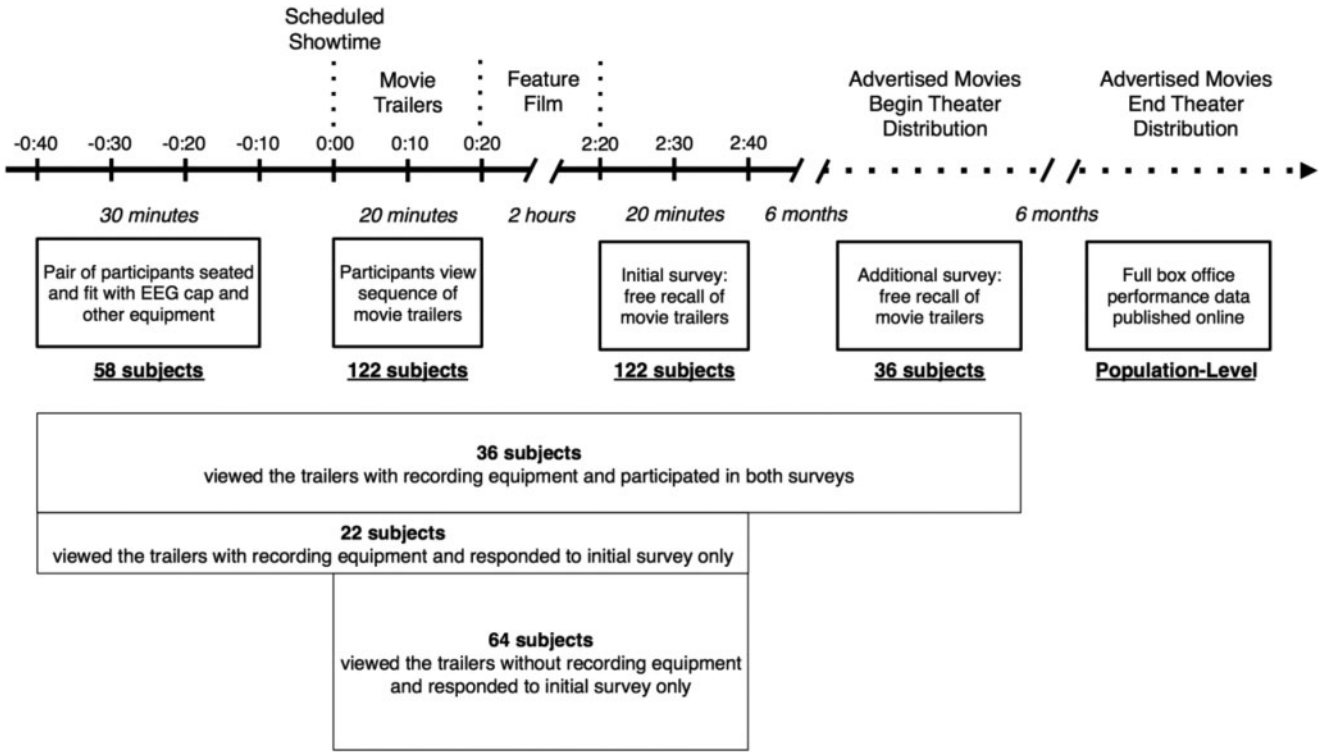

electrode would light red (see appendix figure 1) indicating that conductive gel needed to be applied at that site. Gel was applied via a syringe and a blunt needle, which was shown to participants to alleviate any potential concerns. Additionally, the experimenters preferred to call the needle a "tube" to avoid raising any alarm. A pea-sized amount of gel usually sufficed to establish electrical conduction at a given site, but the process required practice and patience. The first two sites to apply gel needed to be the ground (Gnd, black) and reference (Ref, blue) electrodes; after gel was sufficiently applied to both of those sites, their LEDs turned green. Then, gel was applied to the 32 data-collecting electrodes; each site's LED turned green when it had enough gel to conduct the signal (i.e., sufficiently low impedance). Once all LEDs were green, which took approximately 15 minutes per participant (best to perform this step in parallel for both participants given the time constraints), the signal button (denoted with a circled ∼) was pressed. EEG recording was then initiated from the system's software suite on a laptop connected to the equipment.

6. The other physiological recording equipment was connected to each participant. For the cardiac data collection, participants were instructed to place three electrode leads under clothing on either side of the chest and on the lower-left abdomen, forming a triangle around the heart. For the respiratory data collection, participants were asked to place an expandable band around their torso just below their chest. For the electrodermal activity recording, electrodes were taped to the index and middle fingers of the participant's nondominant hand. These electrodes were connected to a relay device worn like a watch around the wrist. Lastly, a video camera was placed near the movie screen, angled and zoomed to view the participants. All of these devices were recording before the scheduled showtime.
7. At the scheduled showtime, preselected audiovisual stimuli were presented, including movie trailers, other advertisements, and ultimately the feature film. Participants were asked to refrain from eating, drinking, or performing any other unusual movements (e.g., standing up) that could interfere with the recordings.
8. Immediately at the conclusion of the movie, participants were asked to respond to a surprise survey. They remained seated and completed this survey on a clipboard while all equipment continued to collect data.
9. After the surveys were completed, all recording equipment was shut down and disconnected from the participants.
10. Participants were offered wet towels to clean the gel from their scalp at the conclusion of the viewing session.

# FIELD STUDY TIMELINE AND DATA OVERVIEW

**APPENDIX FIGURE 3**

FIELD STUDY TIMELINE, KEY DATA, AND PARTICIPANT COUNTS




# EEG MONTAGE

This figure depicts a top-down, two-dimensional view of the approximate electrode locations across a participant's scalp with a cartoon nose and ears to orient the reader (actiCAP 64Ch Standard-2 green holders, Brain Products GmbH, Gilching, Germany). At each site, we list our channel reference number above the corresponding standard EEG label. F, P, T, O, and C in the EEG labels are anatomical abbreviations corresponding to the Frontal lobe, Parietal lobe, Temporal lobe, Occipital lobe, and Central regions. Pairs of these letters indicate a location between the two indicated regions. Electrode channels 1 and 2 are labeled with the abbreviation Fp (frontal polar sites). Locations represented outside of the outline correspond with sites further down a participant's head. A ground electrode (Gnd) and a reference electrode (Ref) are respectively represented in gray text at AFz (anterior frontal midline) and FCz (frontal/central midline).

The following two tables present the predictive power of CBC calculated using various subsets of the 32 recording electrodes in our case study. "Channel count" indicates the

**APPENDIX FIGURE 4**

NUMBERED AND LABELED ELECTRODE SITES USED IN CASE STUDY

**APPENDIX TABLE 1**

CBC FROM VARIOUS MONTAGES PREDICTS TRAILER RECALL

| | | Correlation between CBC and trailer recall | | | | |
|---|---|---|---|---|---|---|
| | | Average | | Optimal montage | | |
| Channel count | Possible montages | *r* | *p* | Channels | Max *r* | Min *p* |
| 32 | 1 | 0.66 | 0.01 | All | 0.66 | 0.01 |
| 31 | 32 | 0.66 | 0.01 | All except 22 | 0.69 | 0.01 |
| 30 | 496 | 0.66 | 0.02 | All except 1, 22 | 0.71 | 0.01 |
| 29 | 4,960 | 0.65 | 0.02 | All except 1, 22, 24 | 0.73 | < 0.01 |
| 28 | 35,960 | 0.65 | 0.02 | All except 1, 19, 22, 27 | 0.76 | < 0.01 |
| 27 | 201,376 | 0.65 | 0.02 | All except 12, 14, 19, 22, 27 | 0.75 | < 0.01 |
| 26 | 906,192 | 0.64 | 0.02 | All except 1, 19, 22, 24, 29, 30 | 0.77 | < 0.01 |
| 25 | 3,365,856 | 0.64 | 0.02 | All except 1, 19, 21, 22, 23, 27, 29 | 0.78 | < 0.01 |
| 24 | 10,518,300 | 0.64 | 0.02 | All except 1, 2, 9, 22, 23, 24, 27, 29 | 0.79 | < 0.01 |
| 23 | 28,048,800 | 0.63 | 0.03 | All except 1, 4, 11, 14, 16, 20, 22, 24, 27 | 0.79 | < 0.01 |
| 22 | 64,512,240 | 0.63 | 0.03 | All except 1, 2, 4, 8, 9, 14, 16, 24, 17, 30 | 0.80 | < 0.01 |
| 21 | 129,024,480 | 0.62 | 0.02 | All except 1, 4, 9, 11, 12, 14, 16, 20, 22, 27, 29 | 0.82 | < 0.01 |
| 20 | 225,792,840 | 0.62 | 0.03 | All except 1, 9, 10, 14, 16, 19, 21, 22, 24, 26, 27, 29 | 0.81 | < 0.01 |
| 19 | 347,373,600 | 0.61 | 0.03 | All except 1, 4, 8, 9, 10, 14, 15, 19, 22, 26, 27, 29, 30 | 0.84 | < 0.01 |
| 18 | 471,435,600 | 0.60 | 0.04 | All except 1, 4, 8, 10, 12, 14, 15, 18, 19, 22, 23, 27, 29, 30 | 0.82 | < 0.01 |
| 17 | 565,722,720 | 0.60 | 0.04 | All except 1, 2, 4, 9, 11, 14, 16, 17, 19, 22, 23, 27, 30, 31, 32 | 0.84 | < 0.01 |
| 16 | 601,080,390 | 0.59 | 0.04 | 2, 4, 5, 6, 7, 8, 10, 11, 15, 17, 18, 21, 25, 28, 30, 32 | 0.85 | < 0.01 |
| 15 | 565,722,720 | 0.58 | 0.05 | 2, 4, 5, 6, 7, 8, 10, 15, 17, 18, 19, 20, 25, 29, 32 | 0.83 | < 0.01 |
| 14 | 471,435,600 | 0.57 | 0.06 | 5, 6, 7, 10, 12, 14, 15, 18, 19, 23, 25, 26, 31, 32 | 0.85 | < 0.01 |
| 13 | 347,373,600 | 0.56 | 0.06 | 5, 6, 7, 8, 9, 12, 13, 17, 21, 25, 26, 28, 31 | 0.88 | < 0.01 |
| 12 | 225,792,840 | 0.55 | 0.07 | 5, 6, 7, 11, 12, 15, 18, 23, 24, 25, 29, 32 | 0.86 | < 0.01 |
| 11 | 129,024,480 | 0.54 | 0.08 | 6, 7, 8, 12, 13, 18, 21, 25, 26, 29, 32 | 0.85 | < 0.01 |
| 10 | 64,512,240 | 0.53 | 0.09 | 2, 5, 6, 8, 15, 17, 18, 20, 25, 26 | 0.85 | < 0.01 |
| 9 | 28,048,800 | 0.51 | 0.10 | 5, 6, 11, 17, 18, 21, 23, 25, 28 | 0.84 | < 0.01 |
| 8 | 10,518,300 | 0.49 | 0.12 | 6, 7, 12, 14, 15, 17, 23, 25 | 0.89 | < 0.01 |
| 7 | 3,365,856 | 0.47 | 0.15 | 5, 7, 18, 19, 25, 26, 32 | 0.87 | < 0.01 |
| 6 | 906,192 | 0.45 | 0.17 | 2, 6, 12, 15, 20, 28 | 0.84 | < 0.01 |
| 5 | 201,376 | 0.42 | 0.21 | 2, 5, 17, 20, 32 | 0.85 | < 0.01 |
| 4 | 35,960 | 0.39 | 0.25 | 5, 7, 15, 25 | 0.88 | < 0.01 |
| 3 | 4,960 | 0.35 | 0.31 | 17, 25, 23 | 0.84 | < 0.01 |
| 2 | 496 | 0.30 | 0.38 | 17, 25 | 0.81 | < 0.01 |
| 1 | 32 | 0.23 | 0.48 | 26 | 0.60 | 0.03 |

number of recording electrodes in a montage. We used all 32 electrodes (the first row of the table) in the case study. For a given channel count, we report the total number of configurations that can be formed ("Possible montages"), which equals 32 choose the given channel count (e.g., 32 choose 30 = 496). For each of the possible montages for a given channel count (or a random sample of 5,000 configurations when there were more than 35,960 possible montages), we calculated the CBC and its correlation with trailer recall (for appendix table 1) or weekly ticket sales (for appendix table 2), and the "Average" column lists the mean *r* and *p* values across all evaluated montages. Under "Optimal montage," we list the channels (by reference number; see appendix figure 4) in the configuration of electrodes that resulted in the highest correlation, which is listed under "Max *r*" along with its corresponding "Min *p*."

In both of the following tables, CBC's correlation with the dependent variable (e.g., trailer recall or weekly ticket sales) remains statistically significant ($\leq .05$) on average even with half of the channels randomly removed. Additionally, for every channel count, there was an optimal montage for which CBC and the dependent variable had a statistically significant correlation. In other words, even with fewer than 32 recording electrodes, our case study data suggests that there is always a way to place electrodes into a montage that enables our method to be used effectively.

**APPENDIX TABLE 2**

CBC FROM VARIOUS MONTAGES PREDICTS WEEKLY TICKET SALES

| | | Correlation between CBC and weekly ticket sales | | | | |
|---|---|---|---|---|---|---|
| | | Average | | Optimal montage | | |
| Channel count | Possible montages | *r* | *p* | Channels | Max *r* | Min *p* |
| 32 | 1 | 0.68 | 0.01 | All | 0.68 | 0.01 |
| 31 | 32 | 0.67 | 0.01 | All except 19 | 0.71 | 0.01 |
| 30 | 496 | 0.67 | 0.01 | All except 3, 19 | 0.73 | < 0.01 |
| 29 | 4,960 | 0.67 | 0.01 | All except 6, 9, 19 | 0.75 | < 0.01 |
| 28 | 35,960 | 0.66 | 0.01 | All except 5, 6, 9, 19 | 0.77 | < 0.01 |
| 27 | 201,376 | 0.66 | 0.02 | All except 5, 6, 9, 19, 26 | 0.78 | < 0.01 |
| 26 | 906,192 | 0.66 | 0.02 | All except 2, 3, 6, 19, 23, 24 | 0.79 | < 0.01 |
| 25 | 3,365,856 | 0.65 | 0.02 | All except 2, 3, 12, 19, 23, 24, 29 | 0.79 | < 0.01 |
| 24 | 10,518,300 | 0.65 | 0.02 | All except 5, 6, 9, 11, 19, 23, 26, 30 | 0.81 | < 0.01 |
| 23 | 28,048,800 | 0.64 | 0.02 | All except 4, 6, 7, 9, 12, 19, 23, 26, 29 | 0.81 | < 0.01 |
| 22 | 64,512,240 | 0.64 | 0.03 | All except 2, 4, 6, 9, 12, 18, 19, 22, 23, 26 | 0.83 | < 0.01 |
| 21 | 129,024,480 | 0.63 | 0.03 | All except 1, 2, 3, 5, 6, 9, 18, 19, 24, 26, 28 | 0.83 | < 0.01 |
| 20 | 225,792,840 | 0.63 | 0.03 | All except 2, 3, 5, 6, 9, 11, 19, 20, 21, 22, 23, 30 | 0.83 | < 0.01 |
| 19 | 347,373,600 | 0.62 | 0.04 | All except 2, 5, 6, 8, 9, 11, 18, 19, 22, 23, 24, 25, 30 | 0.85 | < 0.01 |
| 18 | 471,435,600 | 0.61 | 0.04 | All except 1, 2, 3, 6, 8, 9, 11, 18, 22, 23, 24, 25, 26, 29 | 0.86 | < 0.01 |
| 17 | 565,722,720 | 0.60 | 0.05 | All except 1, 2, 3, 5, 6, 8, 9, 11, 20, 21, 22, 23, 24, 26, 29 | 0.86 | < 0.01 |
| 16 | 601,080,390 | 0.60 | 0.05 | 4, 7, 8, 11, 13, 14, 17, 18, 21, 22, 25, 26, 27, 28, 31, 32 | 0.84 | < 0.01 |
| 15 | 565,722,720 | 0.59 | 0.06 | 4, 5, 11, 14, 15, 16, 17, 18, 20, 21, 25, 27, 30, 31, 32 | 0.86 | < 0.01 |
| 14 | 471,435,600 | 0.58 | 0.06 | 4, 7, 8, 12, 13, 14, 15, 16, 18, 22, 23, 27, 31, 32 | 0.88 | < 0.01 |
| 13 | 347,373,600 | 0.57 | 0.07 | 1, 7, 10, 14, 15, 16, 17, 20, 21, 26, 27, 28, 31 | 0.87 | < 0.01 |
| 12 | 225,792,840 | 0.56 | 0.09 | 3, 4, 13, 14, 15, 16, 17, 18, 25, 27, 28, 31 | 0.90 | < 0.01 |
| 11 | 129,024,480 | 0.54 | 0.10 | 6, 7, 8, 11, 14, 15, 16, 21, 27, 28, 30 | 0.86 | < 0.01 |
| 10 | 64,512,240 | 0.53 | 0.11 | 3, 7, 13, 14, 15, 16, 24, 27, 30, 31 | 0.87 | < 0.01 |
| 9 | 28,048,800 | 0.51 | 0.13 | 2, 14, 15, 17, 24, 27, 28, 31, 32 | 0.88 | < 0.01 |
| 8 | 10,518,300 | 0.50 | 0.15 | 7, 8, 10, 14, 15, 26, 27, 28 | 0.87 | < 0.01 |
| 7 | 3,365,856 | 0.47 | 0.18 | 2, 14, 15, 16, 17, 28, 32 | 0.90 | < 0.01 |
| 6 | 906,192 | 0.45 | 0.20 | 10, 14, 15, 21, 27, 31 | 0.89 | < 0.01 |
| 5 | 201,376 | 0.42 | 0.23 | 10, 14, 15, 21, 31 | 0.89 | < 0.01 |
| 4 | 35,960 | 0.39 | 0.27 | 14, 15, 16, 31 | 0.92 | < 0.01 |
| 3 | 4,960 | 0.35 | 0.30 | 14, 15, 31 | 0.89 | < 0.01 |
| 2 | 496 | 0.30 | 0.34 | 14, 15 | 0.83 | < 0.01 |
| 1 | 32 | 0.22 | 0.39 | 15 | 0.70 | 0.01 |

# CARDIAC, RESPIRATORY, AND ELECTRODERMAL DATA

**APPENDIX TABLE 3**

CORRELATIONS OF PHYSIOLOGICAL DATA WITH CBC, RECALL, AND SALES

| | | Correlation with physiological data | | |
|---|---|---|---|---|
| Physiological data | | CBC | Trailer recall | Weekly ticket sales |
| Cardiac | Average activity level | –0.14 | 0.03 | –0.10 |
| | Correlation across subjects | –0.20 | –0.05 | –0.44 |
| Respiratory | Average activity level | 0.49* | 0.22 | 0.21 |
| | Correlation across subjects | –0.10 | –0.03 | 0.15 |
| Electrodermal | Average activity level | 0.09 | 0.03 | 0.35 |
| | Correlation across subjects | 0.30 | 0.28 | 0.39 |

*The correlation between the average respiratory activity level and CBC throughout the movie trailers had a *p*-value of .09. All other correlations had *p*-values over .10.

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