Can Media Synchronize Our Physiological Responses?

Skin Conductance Synchrony as a Function of Message Valence, Arousal, and Emotional Change Rate

To cite this article: Han, J., Lang, A., & Amon, M. J. (2022) Can media synchronize our physiological responses? Skin conductance synchrony as a function of message valence, arousal, and emotional change rate, *Communication Monographs, 89*:1, 47-69, DOI: 10.1080/03637751.2021.1942105

Jingjing Han (Ph.D., Indiana University, Bloomington), Researcher, School of Journalism and Institute for Global Communications and Integrated Media, Fudan University, Shanghai, China, hanjing@indiana.edu (corresponding author).

Annie Lang (Ph.D., University of Wisconsin, Madison), Distinguished Professor, The Media School, Indiana University Bloomington, IN, United States, anlang@indiana.edu.

Mary Jean Amon (Ph.D., University of Cincinnati), Assistant Professor, School of Modeling, Simulation and Training, University of Central Florida, FL, United States, mamon@ist.ucf.edu

Acknowledgements:

This work was supported by the Indiana University College of Arts and Sciences Dissertation Completion Fellowship. The authors thank Minkyo Lee for selecting and pre-testing the stimuli, Seung Woo Chae, George Christian Roberson, Yang (Slash) Shi, Yaojun (Harry) Yan for their help on data collection.

Abstract

(Word count: 119 words)

Guided by nonlinear dynamical systems theory (NDST), this study examined the degree to which media can synchronize individuals' emotional arousal responses (as indicated by skin conductance) during video viewing as a function of message valence, arousal, and emotional change rate. Data from 490 paired dyads created from 45 participants were analyzed. We used cross recurrence analysis (a nonlinear dynamical analysis) to capture the dynamics of physiological synchrony. Results show that calm compared to arousing messages and negative arousing compared to positive arousing messages generated stronger, more deterministically structured, and more stable skin conductance synchrony. Fast compared to slow changes in emotion generated stronger but not necessarily more deterministic and stable skin conductance synchrony. Theoretical and practical implications are discussed.

Keywords: physiological synchrony, media viewing, cross recurrence analysis, dynamic systems, skin conductance

(Word count for the main body: 8488 words)

Can Media Synchronize Our Physiological Responses? Skin Conductance Synchrony as a Function of Message Valence, Arousal, and Emotional Change Rate

Media research has long been concerned with whether media use makes people think alike. The agenda setting theory suggests that media tell people what to think about (McCombs & Shaw, 1972) and how to think about public issues (McCombs et al., 1997), thereby synchronizing people's attention to and processing of those issues. Similarly, cultivation theory argues that heavy television viewing increases the similarity of viewers' thoughts (*mainstreaming effect*, Gerbner et al., 1980). More recent research suggests that the increased use of mobile devices causes users to consume more similar content, resulting in more similar thinking and decision making (Yang et al., 2020). But little research has been paid to the question of whether media synchronize us physiologically and emotionally and, if so, how those self-reported similarities in thinking are associated with similarities in physiological and emotional reactions toward media. Yet we know that media has powerful effects on people's emotions and that emotions have powerful effects on how people think (Lang, 2006). Therefore, asking the question—can media synchronize viewers' physiological states—should be fundamental to understanding the extent to which media use brings about similarity and synchrony.

Recent research has begun to investigate the synchronicity of embodied responses in a number of areas. Scholars approach the question from two perspectives (Hasson & Frith, 2016). One examines the extent to which individuals' neural, physiological, emotional, and behavioral activities become synchronized as a result of interpersonal interaction. Theoretical mechanisms underlying interpersonal-interaction-driven synchronization include mirror neurons, emotional contagion, and interpersonal emotional processing (e.g., Butler, 2011; Hatfield et al., 1993;

Schoenewolf, 1990). The second perspective (used in this study) seeks to understand the extent to which an external driver can synchronize the responses of multiple individuals. A growing number of studies show that media can function as an external driver to synchronize a variety of individual responses. For example, individuals viewing movies, television programs, images, or listening to audio recordings have been shown to have synchronized neural activity (Hasson et al., 2004; Hasson et al., 2010; Weber et al., 2009), heart rate (Creaven et al., 2014), skin conductance level (SCL; Golland et al., 2014), emotional experiences (Wild et al., 2001), and eye blinks (Nakano et al., 2009).

Although researchers have provided ample evidence that media is able to generate neural, physiological, and behavioral synchronization across individuals when they view or listen to media alone, the types of information in media that lead to increased or decreased synchronization remains unclear. Media narratives (Weber et al., 2015) and emotional content in media (Golland et al., 2014) are two suggested drivers for synchronizing neural and physiological activities. Golland and colleagues (2014) have found that compared to nature scenes, horror movies elicited more synchronous heart rate and SCL whereas comedies increased heart rate but not SCL synchrony. The dimensional theory of emotion conceptualizes three dimensions underlying human emotion: emotional valence, arousal, and dominance, of which valence and arousal explain the largest proportion of the variance in self-reported emotional responses and are correlated with physiological responses (Bradley & Lang, 2000). To date, differences in how the valence (positive vs. negative) and level of arousing content in media messages alters physiological synchrony have yet to be studied.

Other research has begun to investigate how viewers' individual differences influence the level of interpersonal synchrony in the solitary viewing context. For example, Parkinson et al.

(2018) found that when pairs of individuals viewing movies separately were created, those with smaller social distance scores had more synchronous neural responses. The authors suggested that the similarity of brain responses during movie viewing might be used to predict strength of friendship. Hasson and his colleagues proposed that the brain synchronization between individuals could be used as a benchmark to detect abnormalities (Hasson et al., 2010). For example, they found more brain synchronization between two healthy individuals than between one healthy and one autistic patient.

This paper proposes that much of the interpersonal synchronization seen between individuals viewing separately is caused by the structural and emotional content in video messages. In this study, we tested the ability of message valence, arousal, and rate of emotional change to elicit SCL synchrony between individuals viewing the messages separately. *SCL synchrony* is defined as the temporal similarity between two individual viewers' skin conductance level. In this study the viewers were viewing alone – thus the only synchrony driver is the media message, there is no interpersonal interaction between the viewers. We approached this synchrony-driven-by-media question from a nonlinear dynamic systems perspective. The dynamic system in the solitary viewing context is a human-medium-message system that consists of a human, a message, and a medium embedded in a place (Lang, 2014). The theoretical foundation for this solitary television viewing synchronization investigation comes from NDST and from the limited capacity model of mediated message processing (LC4MP, Lang, 2006). First, the prediction from NDST is that reducing the degrees of freedom in a system decreases complexity and increases order/synchrony. In this study, the degrees of freedom in the human-medium-message system are reduced by exposing participants to the same media messages thus constraining the amount of audio and visual perceptual information to the information in the messages. Second, according to the LC4MP, both structural and emotional content in media messages elicits automatic attention and emotion responses which are indexed by predictable changes in skin conductance. These ongoing dynamic automatic responses should result in increased SCL synchrony. Specifically, viewing media in a lab setting restricts people's physical behaviors and perceptual information making the system less complex. Structural features of media such as cuts, edits, and voice changes elicit automatic orienting responses in viewers, which are characterized by a slowing of the heart rate and an increase in skin conductance activity. Similarly, intense emotional media content elicits automatic changes in heart rate and skin conductance for all viewers. Thus, viewers processing the same perceptual information separately but in the same viewing context, should demonstrate a higher level of synchrony than those not viewing the same messages or in other contexts.

SCL Synchrony and Emotional Media

Research has shown that changes in emotional valence and arousal and in the structural features of the visual and auditory content (e.g. camera and voice changes) leads to automatic changes in skin conductance activity. For example, humans have greater skin conductance changes when viewing emotional images compared to neutral images, and when viewing negative and/or arousing images compared to positive and/or calm images (Bradley, Codispoti, Cuthbert, et al., 2001; Bradley, Codispoti, Sabatinellie, et al., 2001). Individuals' skin conductance activity can also be altered by many orienting eliciting structural features in messages such as voice changes, audio production effects, camera changes, perspective changes, and form changes (Lang et al., 2000, 2007; Potter et al., 2008). In the human-medium-message system, medium and message are the two factors influencing the solitary medium viewer. In this case, the medium, television, reduces the degrees of freedom because it is an audio visual medium and thereby elicits automatic responses in the audio and visual perceptual systems. The context that a person is viewing television alone is a constant of the system. The message, however, is changing dynamically and thereby continuously influencing skin conductance through momentary changes in structural features and emotional content which should lead, over time, to SCL synchrony between individual viewers.

Previous research has shown that the SCL of a given individual viewing video alone is significantly correlated with SCL averaged across all other individuals (Golland et al., 2014). In this study we extended that work by examining not just the ability of video to elicit synchrony between paired solitary viewers but also how changes in message valence, arousal, and rate of change in message valence and arousal can change the level of media-driven SCL synchrony overtime.

Cacioppo and Berntson’s (1994) model of emotion and motivation suggests that humans evolved to automatically attend to positive (opportunities) and negative (threats) information in the environment. However, their responses to positive and negative information are not the same. Humans respond more quickly and intensely to negative information compared to positive information because negative information is often more consequential. Failure to obtain food or a mate is less serious than failure to avoid a predator. Because negative events elicit faster and stronger cognitive, emotional, and behavioral responses, they should elicit more synchronized responses compared to positive information. Similarly, Fredrickson’s (2001) broaden-and-build theory predicts that positive emotion broadens the scope of attention and memory (i.e. enlarges one’s area of focus and facilitates one’s ability to recall positive memories), and elicits novel and exploratory thoughts and actions, leading to greater variation in responses across individuals whereas negative emotion narrows attention and restricts processing styles, resulting in less variation in responses and likely resulting in stronger synchrony across individuals. Research has demonstrated more highly correlated individual neural responses among movie viewers during negative compared to positive movies (Nummenmaa et al., 2012). Accordingly, we hypothesized:

> **H1:** Individuals viewing television separately would have stronger SCL synchrony with one another during negative videos compared to positive videos.

Similarly, message arousing content level should also influence SCL synchrony. Compared to calm content, viewers more easily detect and attend to arousing content, leading to more attention to media (indicated by larger heart rate deceleration) and higher physiological arousal (indicated by skin conductance, Lang, 2006). In other words, increased emotional intensity in media content increases the number and magnitude of orienting responses and skin conductance responses, which may lead to higher SCL synchrony between viewers. Research has also demonstrated that arousing movies increase interpersonal synchrony in somatosensory cortices and in visual and dorsal attention networks (Nummenmaa et al., 2012). Hence, we predicted:

> **H2:** Individuals viewing television separately would have stronger SCL synchrony with one another during arousing videos compared to calm videos.

According to NDST, the trajectory of any dynamic system depends not only on its current state but also on its history, which is known as the hysteresis effect (Strogatz, 1994). In particular, many dynamic systems demonstrate a sensitive dependence to initial conditions, whereby small differences in initial parameters or positions grow exponentially over time and lead to distinctly different outcomes (Strogatz, 1994). The hysteresis effect is present in many fields including mechanics, engineering, physics, chemistry, human movement, and psychology. In communication science we are already well acquainted with the hysteresis effect. We have a variety of theories and concepts depicting and demonstrating the existence of message order (sequence) effects. For example, excitation transfer theory (Zillmann, 1971) shows that the activated excitation from one message can be carried over to subsequent messages. Mood congruency (Bower, 1981) shows that people in positive moods have better recall for positive events whereas those in negative moods have better recall of negative events. Literature also highlights human message processing as varying based on the sequence in which messages are presented, leading to different patterns of emotional and cognitive processing (e.g., Lang et al., 2013; Wang & Lang, 2012). Moreover, rate of change between emotional states can have implications for the duration of recovery from a given emotion, where fast-changing switches leads to faster recovery (Pettersson et al., 2013). Thus, previous findings support the notion that individual differences in initial conditions and historical variation influence message effects. When reconceptualizing human communication as a complex dynamic system, hysteresis becomes a universal law underlying previous order-effect findings.

In this study we examined two different orders of message presentation that differ in their rate of emotional changes, with the goal of examining the extent to which hysteresis is present and contributes to our understanding of the “order effect” commonly observed in communication studies. Because structural and emotional changes in media influence skin conductance activity, as we discussed earlier, a message sequence with faster and more frequent changes in emotional content should lead to faster and more frequent changes in viewers’ emotion and attention. More importantly, those response changes should be dynamically aligned because they are automatically elicited by changes in the message. Thus, we hypothesized that a faster emotional change in media content will better reduce variabilities in individual viewers’ perceptual, motivational, emotional, and cognitive systems, resulting in fewer degrees of freedom and greater synchrony across individuals. Hence, we proposed that,

H3: Faster changes in emotional content would generate stronger synchrony for individuals viewing television separately.

Determinism and Stability of Synchrony

The importance of analyzing and understanding media users' cognitive, emotional, and behavioral changes over time in media research is increasingly noted among subfields of communication research. NDST assumes that elements in the system are continuously changing and dynamically interacting with one another over time (Strogatz, 1994). Certain patterns might emerge from the system at one time point and disappear at another time. Therefore, understanding what patterns a system can exhibit and how patterns change over time becomes critical for understanding a dynamic system. Examining patterns in time requires researchers to understand the extent to which the patterns they see are *stable*, in terms of how long patterns endure, and *deterministic*, meaning the observed patterns are driven by the system itself rather than by randomly occurring processes.

NDST suggests that systems including neurological, physiological, cognitive, emotional, and behavioral systems are not only linearly increasing and decreasing from certain aspects, but also nonlinearly shift from one qualitative state to another. Identifying the relative stability of different states indicates the ease with which a system switches from one qualitative state to another when perturbed. Stable states (called attractors) are those that cannot be easily perturbed by external forces, whereas an unstable state is one that can be easily perturbed to shift the system into a new and distinct pattern. State stability can be considered a type of system variability, or likelihood of shifting in-and-out of particular states (Riley & Turvey, 2002). Traditional conceptualizations of variability often equate variability to random noise, with an implicit assumption that variability should be minimized to avoid obscuring the signal of interest. In contrast, NDST provides a number of tools for understanding historical variation, or systematic change over time, by recognizing variability as foundational to understanding system-level processes (Riley & Turvey, 2002). Hence, stability versus instability reveals essential structures and patterns of a system that aggregated statistics are not able to, providing a new lens through which to understand nonlinear dynamics commonly observed in complex systems, including human-technology/media interactions.

Determinism is the degree a system's future states are predictable based on its previous states (Riley & Turvey, 2002; Webber & Zbilut, 2005). In this way, measures of determinism differentiate between the extent to which novel dynamics are generated from the system (low determinism), versus the extent to which future states of a system is determined by its past and present states (high determinism; Riley & Turvey, 2002), where randomness is the antonym of determinism. Notably, this system-level feature is not captured by traditional statistics such as standard deviations as a standard deviation can be predictable and "determined" by the system itself without any random processes. For example, a sine wave and a flat line have the exact same mean but a difference in variance, even though both of them are generated by deterministic systems. Similarly, stability and determinism are overlapping but separable concepts. On the one hand, they both characterize dynamic processes of a system. On the other hand—as illustrated by the previous sine wave example—a system can have low stability as changing over time with ease while having high determinism in moving predictably between those various values. The Method section provides detailed explanations of CRQA metrics for determinism and stability.

To date, we know little about the determinism and stability of media-driven-synchrony as a function of emotional content. However, it seems likely that when there are more message features (such as emotional content and change in emotional content) that elicit automatic responses, the system will be more deterministic. Because we tend to get narrower and stronger responses during negative compared to positive messages, during arousing compared to calm messages, and during change from one type of emotion to another, we expected these conditions to increase both determinism and stability. Hence:

H4a: Negative compared to positive messages would produce more *deterministically structured* SCL synchrony.

H4b: Arousing compared to calm messages would produce more *deterministically structured* SCL synchrony.

H4c: Fast- compared to slow-changing rate would produce more *deterministically structured* SCL synchrony.

H5a: Negative compared to positive messages would produce more *stable* SCL synchrony.

H5b: Arousing compared to calm messages would produce more *stable* SCL synchrony.

H5c: Fast- compared to slow-changing rate would produce more *stable* SCL synchrony.

Method

Experimental Design

This study used data from a large research project that recruited dyads of friends and compared synchrony of solitary and co-viewing participants (Han, 2020). The project was conducted following the University's IRB guidelines (IRB protocol # 1611311746). Only data from the solitary viewers were used for this study. The experiment employed a 2 (message valence: positive and negative) × 2 (message arousal: calm and arousing) × 2 (message repetition) × 2 (emotional change rate: slow and fast) mixed factorial design. Emotional change rate was a between-dyads factor and all other factors were within-dyads factors.

Stimuli

National Collegiate Athletic Association (NCAA) men's basketball games were used as experimental stimuli. In each game, the home university team was one of the two competing teams. A game with the home university team leading was perceived to be positive and a game with the home university team trailing was perceived to be negative. Games with close scores were classified as arousing (score difference ranging from 1 to 4 points) and lopsided games were calm (score difference ranging from 15 to 25 points). Each clip was 3min 40s long and was edited from the last five minutes of each game. To ensure the emotional categorization was correct, 12 possible messages (2 message valence × 2 message arousal × 3 message repetition) were pre-tested (Lee, 2019). 45 undergraduates from the home university came to the lab and were seated in front of a computer screen. Using the Latin square design, each participant watched and rated eight of the 12 videos. After each game, they rated how positive, negative, and aroused the game made them feel on 7-point Likert scales ranging from 1 (*not at all positive/happy/pleased/; not at all negative/unhappy/annoyed; not at all aroused/excited/awake*) to 7 (*extremely positive/happy/pleased; extremely negative/unhappy/annoyed; extremely aroused/excited/awake*, see Lang, Shin, & Lee, 2005). A final set of eight videos from the tested 12 videos that best fit the categories were selected based on participant ratings. A linear mixed-effects model indicated significant main effects of message arousal and valence on emotional ratings. Arousing games (M = 5.43, SE = 1.71) were more arousing than calm games (M = 2.61, SE = .38), F (1, 232) = 209.93, p = .000 < .001. Positive games ($M_{positivity}$ = 4.21, $SE_{positivity}$ = .12; $M_{negativity}$ = 1.35, $SE_{negativity}$ = .13) had higher positivity and lower negativity ratings than negative games ($M_{positivity}$ = 3.28, $SE_{positivity}$ = .12; $M_{negativity}$ = 4.60, $SE_{negativity}$ = .13), $F_{positivity}$ (1, 232) = 458.75, p = .000 < .001, $F_{negativity}$ (1, 232) = 308.26, p = .000 < .001. The arousal and valence emotional manipulation was successful in the main study (Han, 2020).

The experiment had two levels of emotional change rate: slow and fast. In the *slow* condition, emotion was blocked. Participants saw four calm messages (two negative and then two positive) and then four arousing messages (two negative and two positive), so that the arousing content level only changed once and valence only twice over the eight messages. In the *fast* condition, at least one of the emotion factors (arousal or valence) changed for each message, resulting in seven changes in arousing content and four changes in valence. The Online Supplementary Table 1 on our OSF page presents the specific message presentation orders for the emotional change rate factor (https://osf.io/bzkdy/?view_only=4f729811ec9d4110b1de4c1550c6f209).

Procedures

As we mentioned earlier, participants were recruited for the large research project in which dyads of friends from the home university came to the lab together and were randomly assigned to one of the viewing contexts. For dyads who were assigned to the solitary viewing context, two experimenters guided them to different rooms after they consented to participate. After participants were seated, the experimenters began the cleaning procedure in preparation for recording EDA along with other recordings (ECG and facial EMG).[1] The experimenters placed two pre-gelled disposable EDA electrodes on the inner arch of their left foot and connected them to the EDA wires. BIOPAC MP150 systems were used for data collection. Participants began the experiment with one of the randomly assigned emotional change rate conditions. After watching each game, participants answered how aroused, positive, negative, and enjoyable the games made them feel and which team they rooted for. Two two-minute silent baselines were measured, one before and one after watching all the games. Lastly, participants completed a questionnaire with questions of demographics, personality, and basketball knowledge, with course credits or a $10 Amazon gift card as their compensation.

Skin Conductance Level

[1] The cleaning procedures of ECG and facial EMG electrodes were omitted from this manuscript because results of those two signals were not included here. See Han (2020) for more detailed cleaning and electrode placement procedures.

Increased emotional arousal is associated with a higher level of sweat in the eccrine sweat ducts under the skin, leading to lower resistance and faster conductance (Dawson et al., 2007; Potter & Bolls, 2012). EDA data were recorded at a sampling rate of 2000Hz and were synced with each stimulus by creating a digital marker at the onset of each stimulus using BIOPAC. The connect-endpoints method was used via the AcqKnowledge 5.0 software to remove all local artifacts including movement artifacts and pressure changes on the electrodes (Braithwaite et al., 2013). The connect-endpoints method allows researchers to draw a straight line between two data points. Manually drawing lines within small time windows (within one second) can best maintain the original data trajectories while removing local high-frequency fluctuations flagged as artifact. Because EDA is a slow-changing signal, whose response runs on a second-based time scale (Dawson et al., 2007), data was averaged within each second for analysis. This procedure is consistent with other studies that illustrate standard procedures for EDA signal processing (e.g., Choi et al., 2016; Findlay, 2016).

Participants

Twenty-four dyads of friends (48 participants) from the large research project as mentioned above participated the experiment in the solitary viewing context. Data from three participants were deleted because two participants from one dyad did not watch television during the experiment and another participant from a different dyad did not root for rendering the pre-identified valence categories for those games invalid for that participant. This resulted in 45 participants (35 female) with 25 in the slow-changing condition and 20 in the fast-changing condition. Their average age was 19.09 (*SD* = 1.02). Most participants identified themselves as White (*n* = 35, 77.78%), followed by Asians (*n* = 5, 11.11%), and American Indian or Alaska

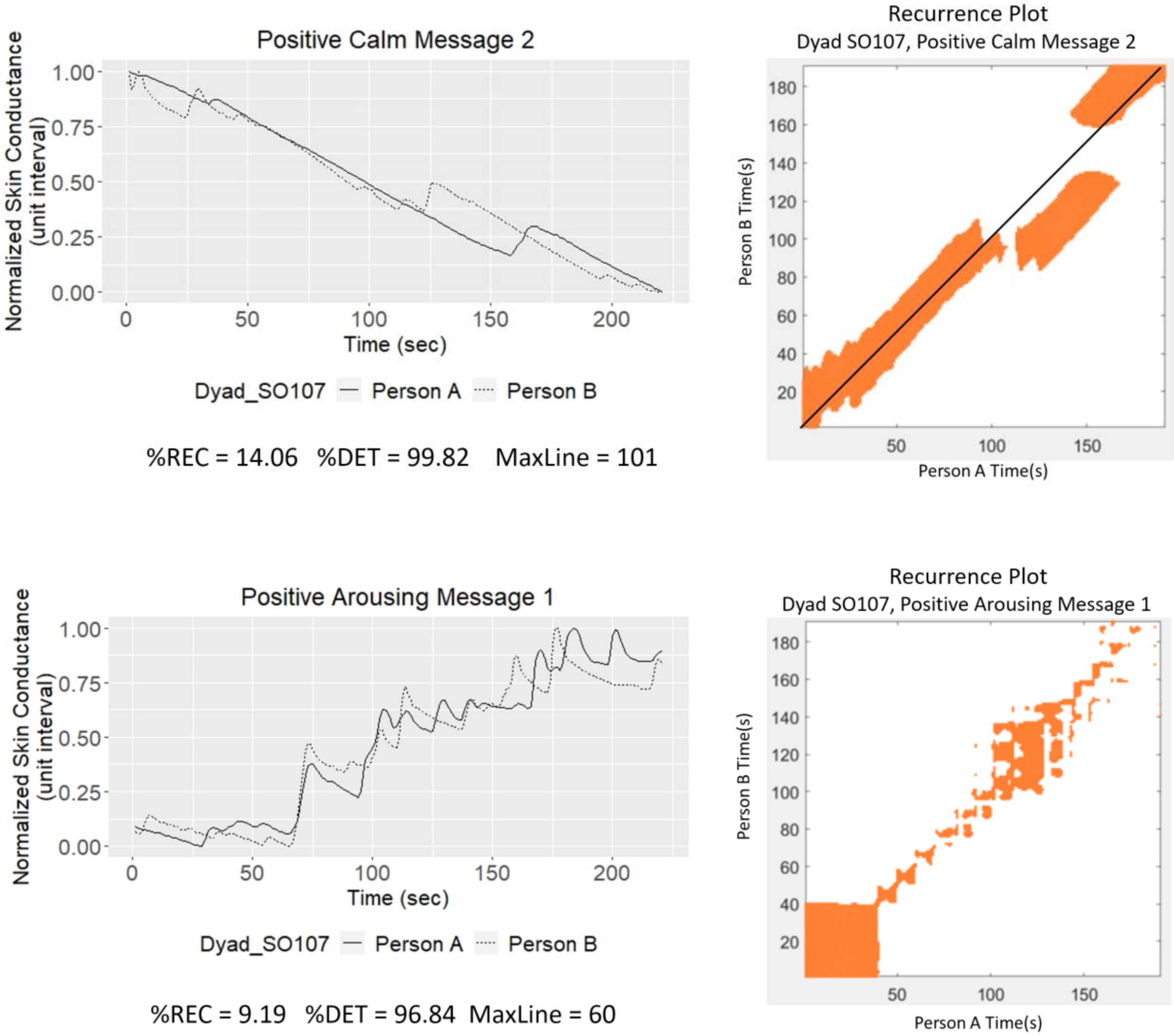
Native (*n* = 1, 2.22%), with *n* = 3 did not report and *n* = 1 was missing as the computer program failed to deliver the demographic questions.

The final *N*. To test our hypotheses with as large a data set as possible, we paired each participant with all other participants in the same rate of emotional change condition, resulting in 490 dyads (i.e., 300 for the slow-changing condition and 190 dyads for the fast-changing condition). Pairing participants within each level of the between-subjects factor (i.e., rate of emotional change) preserved the physiological dynamics that were examined as a basis for physiological synchrony. As a result, all paired dyads in the slow-changing condition remained in the slow-changing condition and similarly, all paired dyads in the fast-changing condition remained in the fast-changing condition. Within the 490 dyads, there were 21 dyads of friends and 469 dyads of strangers. Welch's two-sample *t*-tests and two-sample bootstrap hypothesis testing showed no significant differences between dyads of friends and strangers for any of the three synchrony measures within the relevant time lag of ±15-seconds.

Analytical Procedures

Cross recurrence analysis. To test these hypotheses, we used a nonlinear dynamical tool called cross recurrence quantification analysis (CRQA). Nonlinear analyses are useful for quantifying the types of patterns that exist in over-time data and the characteristics of those patterns (i.e., stability and determinism) as well as assessing the similarity of patterns across multiple systems (e.g., interpersonal synchrony). CRQA has been widely used in both the natural and social sciences (see Webber & Marwan, 2015 for exemplar practices) to calculate the temporal similarity between two time series. Specifically, CRQA compares every point within one time series with every point within another time series, resulting in comparisons across various time lags. When both time series are in a sufficiently similar state at a particular time lag, they are considered to be “recurrent” with one another at that time point. The analysis identifies all the recurrent points, or time points during which the two series are in a sufficiently similar state, resulting in a recurrence plot. Figure 1 shows recurrence plots from our data for two solitary TV viewers’ skin conductance levels when watching the same two videos. Orange points in the recurrence plot indicate a time when the paired participants were in a similar emotional state based on their EDA. The dots on the black diagonal line show recurrent states at lag0 (i.e., synchrony with no time lag). Diagonals further away from lag0 correspond to time series comparisons at increasing time lags. Recurrent states with short time lags are meaningful in the solitary media viewing context because skin conductance responses (SCR) toward external stimuli vary within and between individuals in terms of latency, rise, and recovery time (Dawson et al., 2007). For example, one individual might have a SCR to one specific media scene two or three seconds earlier than another individual. Thus, although their SCRs to the same stimulus occur differently in time, their SCRs suggest that they both respond to the media and therefore should be considered as synchronous responses (or recurrent states).

Figure 1
Exemplar Data



Note. The two graphs on the left are skin conductance level data from one dyad of friends when they viewed television in separate rooms. The right panels are the corresponding recurrence plots from CRQA. The x-axis and y-axis represent time lines for each participant. Each orange dot in the recurrence plots stands for a recurrent state, or a time during which the two participants were in a similar physiological state. The added black line on the top right graph is the main diagonal line of this plot that shows recurrent states at lag0. Orange dots on diagonals further away from the main line represent recurrence states with increased time lags.

To construct the recurrence plot, we used the phase space reconstruction method (Abarbanel, 1996) to create a phase space isomorphic to the real phase space in which the data operates. Phase space reconstruction allows us to recover the phase space from a single time series using the embedding theorem (Takens, 1981). To construct a phase space from a single time series, two steps are required. First, the time delay (τ) needs to be selected using a method called average mutual information (Abarbanel, 1996). In general, τ is selected at a lag where the average mutual information between time series $x(n)$ and $x(n + \tau)$ reaches its first minimum. In other words, at time lag τ, the data of time series $x(n + \tau)$, in theory, has the smallest amount of information about $x(n)$. The idea behind this method is similar to that of the autocorrelation function in linear dynamic analysis which is used to determine the time delay where a future data point $(t + \tau)$ has the least information related to its state at time t. Second, the dimensionality of the phase space needs to be determined using a method called global false nearest neighbors (Abarbanel, 1996). When using one-dimensional time series data, data in higher dimensions in the system are projected onto a single dimension. This method detects false nearest neighbors by adding dimensions until the percentage of false nearest neighbors reaches zero. When it reaches zero, the dimensionality is sufficient to return higher dimensional data to where they belong. Once the phase space has been reconstructed, a distance matrix is created which represents the Euclidean distances between all points in the two time series (see Webber & Zbilut, 2005 for detailed calculation of the distance matrix). Smaller distance values represent points that are closer to one another, which lays the foundation for identifying points that are recurrent to one another. The main diagonal of the distance matrix represents the distances between a given dyads' time series at lag0 (i.e., at the same time), and diagonals further from the main diagonal represent time point comparisons at progressively longer time lags.

The next step is to identify points across the two time series that are recurrent with one other. Because complex systems with continuous values rarely return to the exact same state, a radius is selected, which defines what constitutes a sufficiently similar set of time points. Distance values in the distance matrix below the value of the radius are recoded as recurrent (1), and values greater than the radius are recoded as non-recurrent (0). In this way, a distance matrix is transformed into a recurrence matrix. More details and visual explanations about how one-dimensional time series can be unfolded to higher-level dimensional space and how the radius works to determine recurrence states can be found on our OSF page.

The recurrence plot is used to calculate a variety of measures. Among the most common is the *recurrence percentage* (%REC), or the percentage of recurrent points in the matrix, which we used as an indicator of SCL synchrony with higher %REC indicating greater synchrony. *Percentage of determinism* (%DET) refers to the percentage of recurrence points that form diagonal lines in the plot, representing long-lasting recurrent sequences (as oppose to independent and scattered recurrence dots). In this study, higher %DET indicated the degree to which SCL synchrony was driven by media content versus random/unknown processes. Lastly, *MaxLine* is the maximum number of sequential points in time that are recurrent between paired participants and, thus, indicates stability of synchronization. In this context, high MaxLine indicated greater stability (more resistance to change) in SCL synchrony (see Coco & Dale, 2014 for additional details). Specific calculations of the three measurements from the recurrent plots are formulated below (Marwan et al., 2007; Webber & Zbilut, 2005).[2]

[2] %REC is the rate of recurrence dots found in the plot over the possible dots (i.e., the area of the plot): $\%REC = \frac{1}{N^2}\sum_{a,b=1}^{N} R_{a,b}$ where N is the side length of the plot. Letter a and b represent the time point on the Person A and Person B side, respectively. %DET is the percentage of recurrence dots that consist of diagonal lines (length > 1):

Figure 1 provides two examples from our data set to illustrate the three synchrony measures above. The left two graphs in Figure 1 show one dyad's skin conductance trajectories when watching a calm positive and an arousing positive message with the recurrence plots on the right. The greater number of recurrent points in the positive calm message condition indicate that skin conductance was more synchronized (%REC = 14.06) than during the positive arousing message (%REC = 9.19). The diagonal lines indicate that during the calm positive message condition the dyad was also more deterministic (more connected and less scattered [$\%DET_{\text{calm positive}}$ = 99.82, $\%DET_{\text{arousing positive}}$ = 96.84]). Lastly, the maximum length of the diagonals demonstrate that the dyad was more stable during the calm positive message condition ($MaxLine_{\text{calm positive}}$ = 101, $MaxLine_{\text{arousing positive}}$ = 60).

A MATLAB RQA toolbox developed by Bruce Kay and Michael Richardson (2015) was used to determine the parameters and calculate the three RQA measures. Following the steps outlined above, the *ami.m* program determined 10 data points (equivalent to 10s in our data set) as the time delay for the SCL data and the *fnn.m* program selected four dimensions as the parameter for dimensionality to unfold the skin conductance data in this dataset. To calculate the three measures, the program requires three more parameters. The first one is to choose a normalization method to remove individual differences in the size of the SCL responsivity. A unit interval method was used (Richardson et al., 2007; Webber & Zbilut, 2005). The second parameter requires a distance rescaling method. Distance rescaling is a normalization method to assure that the size and states of the two spaces are comparable. We used the recommended and most commonly used method, maximum distance rescaling (Webber & Zbilut, 2005). The third

---

$\%\text{DET} = \frac{\sum_{l=l_{min}}^{N} l*P(l)}{\sum_{a,b=1}^{N} R_{a,b}}$ where l represents length of a diagonal line and $P(l)$ is the frequency of the length-l diagonal line. MaxLine is the longest diagonal line on the plot, representing the longest period of dyadic synchrony.

parameter is the radius, as explained above. We used a radius of 10% of the maximum distance where most of %REC fell into the preferred 0.5% – 5% range (Richardson et al., 2007; Shockley, 2005). The same parameters were used for all the dyads (Webber & Zbilut, 2005). MATLAB codes and data were shared on our OSF page.

The analysis was conducted for each message, resulting in eight values for each of the three synchrony measures per dyad. Because the distributions of the three recurrence quantifications were skewed, transformation methods were used and outliers were removed using the interquartile range (IQR) criterion for the normal distribution assumption required by linear models. Logit transformation was used for %REC and %DET and square root transformation was used for MaxLine. 1.58% of %REC, 1.22% of %DET, and 0.54% of MaxLine values were identified as outliers and removed (above Q3+1.5 IQR or below Q1−1.5 IQR).

Multilevel modeling (MLM). Multilevel models (or linear mixed-effects models) were used to analyze the hierarchal data structures and control for the interdependence of participants' data that arose from pairing participants with all other participants in the same emotional change rate treatment (Bates, 2010). The model was structured with the following fixed-effect terms: main effects for each message factor, two- and three-way interaction effects of the combinations of message arousal, valence, and rate of emotional change.

The random structure of the model was determined from a process starting with a model with three random-effect terms. The first two random-effect terms were two random intercepts, one for each participant in each dyad, denoted *DyadMember1* and *DyadMember2* in the model. Those random-effect terms were separately specified because each participant was only paired with all the others who were in the same emotional change rate treatment, meaning across the whole data set that has two emotional change rate treatments, each participant was not completely crossed but partially crossed with another participant (Bates, 2010).

The third random-effect term referred to the selected stimuli, allowing each stimulus to have random variation for each RQA quantification. Two different random structures for this third random-effect term were designed and tested. The first stimuli random-effect term provided a random intercept for each stimulus. This model had a high collinearity value with fixed-effect message factors (variance inflation factor > 26), which likely occurred as variance accounted for by the 'stimuli' random intercept largely overlapped with the message arousal and valence factors already accounted for in the model. The second stimuli random-effect term provided a random slope for each message repetition within each category of message valence and arousal but was over fitted. In addition, the ICC for stimuli (ICC = .12) suggests low between-cluster correlations, and that variances explained by the two random effect terms were very low as well (10^{-5} for the random slope and 10^{-2} for the random intercept). Given issues of multicollinearity, overfitting, and low ICC values, the random effect terms for stimuli were excluded from the model. Thus, the final structure of the model included the fixed-effect terms mentioned above plus two random intercepts of participants, one for each participant in each dyad (see Table 1). The Aiken and West's method for simple slope testing was used for post-hoc analysis (Aiken & West, 1991; Page-Gould, 2017). The transformed %REC, %DET, and MaxLine as outcome variables were modeled respectively, with the same structure of fixed effects and random effects for each model. The final dataset and the R program for MLM testing can be found on our OSF page.

Results

Message Valence Effect on Synchrony Strength, Determinism, and Stability

H1, H4a, and H5a predicted that individuals watching negative compared to positive messages would produce higher (H1), more deterministic (H4a), and more stable (H5a) SCL synchrony. All three measures revealed a significant main effect of message valence with a qualifying three-way valence × arousal × emotional change rate interaction effect (see Table 1 for the MLM results and Table 2 for all post hoc analyses for all measures). The interaction effect suggested significantly stronger, more deterministic and stable synchrony, for negative messages than positive messages when the messages were arousing and when the messages were calm in the fast-changing condition (*p*s < .001). When the messages were calm and in the slow-changing condition, negative messages elicited significantly weaker synchrony than positive messages ($p < .001$). Thus, negative messages led to stronger and more deterministic and stable synchrony for three of the four comparisons. H1, H4a, and H5a were partially supported.

Message Arousal Effect on Synchrony Strength, Determinism, and Stability

H2, H4b, and H5b predicted that individuals watching arousing compared to calm messages would generate higher (H1), more deterministic (H4b), and more stable (H5b) SCL synchrony. Like the message valence effect, the three measures revealed a significant main effect of message arousal and the same arousal × valence × emotional change rate interaction mentioned above. Contrary to our predictions, synchrony was significantly stronger, more deterministic and stable for calm compared to arousing messages for all the message conditions (*p*s < .001), though the size of the difference between calm and arousing messages varied as a function of message valence and emotional change rate. In the slow-changing condition, positive messages had a larger arousal effect than negative messages; but in the fast-changing condition, the arousal effect was relatively equal for negative and positive messages (see Figure 2). H2, H4b, and H5b were not supported.

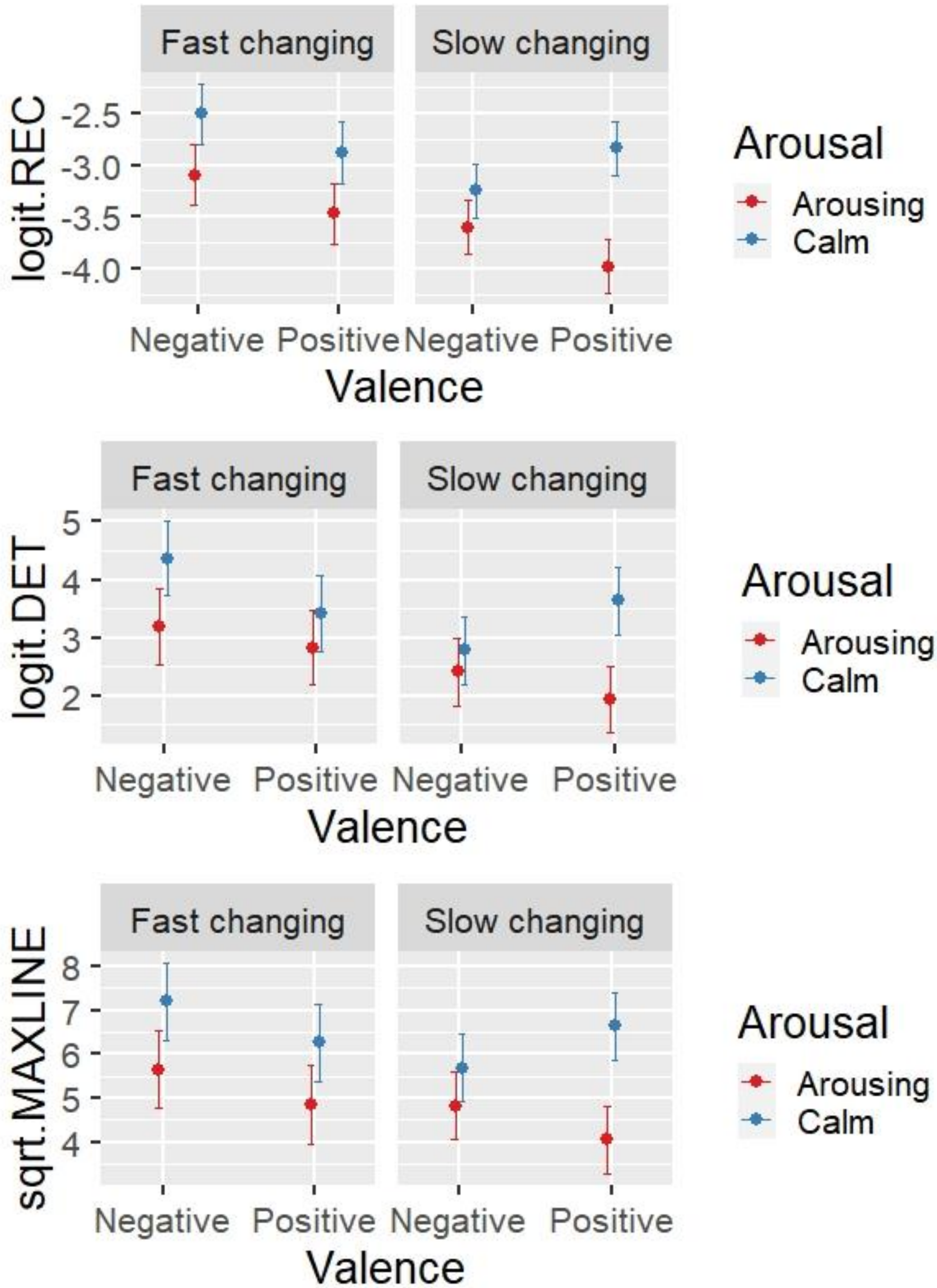
Emotional Change Rate Effect on Synchrony Strength, Determinism, and Stability

H3, H4c, H5c predicted that the fast-changing condition would generate stronger (H3), more deterministic (H4c) and stable (H5c) SCL synchrony than the slow-changing condition. The three synchrony measures showed the same arousal × valence × emotional change rate interaction effect mentioned above. The fast- compared to slow-changing condition had greater, more deterministic and stable SCL synchrony for three out of four types messages (all arousing messages [arousing positive and negative messages] and calm negative messages). This pattern was statistically significant for all the three message types for synchrony strength (*p*s $< .001$), but only two out of three message types for determinism ($p < .001$ for calm negative messages and $p < .05$ for arousing positive messages; $p > .05$ for arousing negative messages), and one message type for stability ($p < .05$ for calm negative messages; $p > .05$ for arousing negative messages and arousing positive messages). For positive calm messages, the fast- compared to slow-changing condition produced equally strong, deterministic and stable synchrony (*p*s $> .05$). Synchrony in the fast-changing condition was stronger in three of the four comparisons, more deterministic in two of the four, and more stable in one of the four comparisons. Thus, H3, H4c, H5c were partially supported.

Figures 2 presents synchrony strength, synchrony determinism, and synchrony stability patterns, respectively. The online supplementary figures show the message valence, arousal, and rate of emotional change effects on synchrony (raw %REC) at different time lags. The synchrony difference as a function of the three message factors was present not only for zero- but also for short time lags within 50-seconds (sometimes reaching to 100-seconds), for all the message conditions that had statistical significance as summarized above.

Figure 2

Arousal × Valence × Emotional Change Rate on the transformed %REC, %DET, and *MaxLine*



Note. Results were tested on transformed %REC and %DET using the logit transformation and on transformed MaxLine using the square root transformation. Larger logit.REC, logit.DET, and sqrt.MAXLINE correspond to larger raw %REC, raw %DET, and longer raw MaxLine, respectively, suggesting stronger synchrony strength, determinism, and stability.

Discussion

This study examined the extent to which viewing media synchronizes SCL synchrony across individuals, by testing the theoretical argument that viewing media reduces the degrees of freedom in the human-medium-message system and increases the frequency and strength of automatic responses elicited by the messages, thereby increasing SCL synchronization between solitary viewers. The primary proposed media drivers of SCL synchronization were emotional valence, arousal, and rate of emotional change. The results support the idea that the three drivers influence the level of SCL synchronization, though the directions of the impact were not always what we predicted. Results indicate that calm messages compared to arousing messages and negative arousing compared to positive arousing messages produce stronger, more deterministic and stable SCL synchrony. Rate of emotional change influenced SCL synchrony strength but not necessarily deterministic structure and stability.

There were a few combinations of our variables in which the results were not in the predicted direction. The first of these results was the direction of the message arousal effect. We found the exact opposite of what we expected with calm messages eliciting stronger synchrony than arousing messages. As we try to understand this result, the silent baseline data (two minutes of data during which participants sat quietly in their individual viewing rooms) provides some important insights. During the silent baselines, most participants' skin conductance data decreased linearly indicating that the individuals were totally calm and probably bored sitting alone in the lab, hence their skin conductance went down. Similarly, when one's favorite team is losing or winning a basketball game by many points (calm messages) enabling the participants to tell the outcome of the game long before it ends, the suspense is gone rendering calm messages more boring and thus more likely to generate this downward trend of SCL than close-fought (arousing) games. We suspect that the higher frequency of this downward trend during calm messages causes the stronger synchrony seen in calm compared to arousing messages. Figure 1 provides one dyad's data demonstrating this possibility. It shows that during the calm message (the top panel), both participants repeated that trajectory of decreasing SCL, resulting in stronger synchrony during the calm (%REC = 14.06) compared to the arousing message (the bottom panel, %REC = 9.19).

This commonly occurring downward trend in SCL mentioned above might also explain the unexpected patterns we see in the effects of message valence and rate of emotional change (see Figure 2). Although the message valence effect was in the direction we expected three out of four times (i.e. negative messages producing stronger, more deterministic and stable synchrony than positive messages), this was not the case for *calm messages in the slow-changing condition* which had stronger, more deterministic and stable synchrony for positive compared to negative messages. During the slow-changing condition, both valence and arousal were blocked. Participants saw four calm games (2 lopsided losses and 2 lopsided wins) first and then four arousing games (2 agonizing defeats and 2 thrilling victories). By the end of the calm negative messages, participants may have been bored due to high score differences, such that they knew their team would fail. Nevertheless, the two additional calm (positive) messages (the doomed-to-win games) following the calm negative ones might make them feel even bored, leading to an even higher possibility for the downward trend of SCL occurring. This might explain why there was increased synchrony when calm messages shifted from negative to positive in the slow-changing condition. Future research can reverse the order of calm negative and calm positive for the slow-changing condition and examine whether calm negative messages lead to stronger synchrony if presented after the calm positive messages. Similarly, this presentation position where the calm positive messages were located in the slow-changing condition might explain the unexpected pattern regarding the effect of emotional change rate. Similarly, unlike all the other message contexts (all arousing messages and calm negative messages) that generated stronger synchrony for fast- compared to slow-changing conditions, calm positive messages were associated with greater synchrony in the slow-changing condition (though not always significantly). Again, this is likely due to the strong downward trend that sets in after the first two “boring” games (calm negative videos). It is worth noting that this relaxed or bored downward trend may be a fairly common state during TV viewing.

The message valence effect on SCL synchrony provides physiological evidence for the broaden-and-build theory (Fredrickson, 2001). Because positive emotion facilitates thinking and initiates novel thoughts and actions, it creates more degrees of freedom in an individual’s behavioral repertoire and makes one’s behavior less predictable. By contrast, negative emotion narrows attention and cognition and therefore restricts the system’s degrees of freedom, reduces behavioral options, and increases the system predictability. As a result, two individuals watching negative messages are more likely to be emotionally and behaviorally synchronized in time. This result concurs with Nummenmaa et al. (2012) who found that negative compared to positive movies enhanced synchrony in brain networks involved with emotional-processing. Together with the previous research, our study suggests that negative emotion elicits greater similarity in responses, narrowing the options for possible responses and actions in a given surrounding (e.g., you only have three choices [freeze, fight or flight] when you encounter a bear in a forest).

We posit that the broaden-and-build theory might also explain the effect of message arousal on SCL synchrony. Like negative emotion, calm emotion may restrict processing and behaviors, as compared to a state of arousal that may result in more varied thoughts and behaviors. At first glance this result might seem contrary to Nummenmaa et al.'s (2012) finding of increased brain synchrony during arousing movies. However, that increased synchrony for arousing movies was found in visual and dorsal attention networks but not in regions such as thalamus, ventral striatum, insula, and so forth (see Nummenmaa et al., 2012). This suggests that the arousal effect in brain synchrony is limited to specific brain regions and is not a global effect. As neurological and physiological activities emerge from the nonlinear process of human system and operate on different timescales, the synchrony patterns as a function of message arousal could be different (Bertenthal, 2007). To increase our understanding of the effect of arousal on neurological and physiological synchrony, future research should examine the effect using different temporal resolution brain scanning techniques such as EEG and fNIRS. Finally, the different analytical strategies that were used to quantify synchrony might be another important reason for the opposite synchrony pattern we see here. Recall the common decreasing trend as discussed above, this linear trend *is* the non-stationarity removed by linear analyses (e.g. cross correlation analysis) that have been used in Nummenmaa et al. and many other studies for synchrony quantification but being captured by the CRQA. Here we see one of the advantages of non-linear analysis: it preserves the nonstationary characteristics that are removed by the requirements of linear methods. Characteristics such as a linear trend, a periodic cycle, or other systematic change in variance are considered to be meaningful data in the non-linear analysis. Consider once again the silent baseline period, here the neutral lab environment constrains individuals' emotional arousal, shifting people to a calm state during which their skin conductance decreases linearly. In the same way, media viewing can bring about linearly increasing or decreasing skin conductance activity. When these trends are removed from previous studies, it eliminates the global impact of media viewing, but those trends are part of the source of entrainment of interest in the present study.

We also found that for most cases, a faster rate of emotional change was better at synchronizing individual viewers. This novel finding provides important theoretical and methodological implications for both message processing and synchrony research. First, it reveals one of the underlying mechanisms embedded in the message sequence effect. Although earlier research has noted the importance of message sequence in message processing, our understanding of how different message sequences influence processing is still extremely limited. Most studies investigating rather than controlling message order, have only examined the effect of how the emotion of a previous message affects processing of the subsequent message. An overall understanding of how changing the order of messages influences the dynamics of message processing is still an uncharged territory. This study shows that the rate of emotional change across messages matters and faster change leads to more similar message processing, though the deterministic structure and stability of synchrony are mostly the same across different rates of emotional changes. Second, it suggests that synchrony research should control emotional change rate within and across messages when testing other effects on physiological synchrony. Failing to do so might result in confounded results.

Unlike previous research that only tested synchrony strength in media viewing contexts, this study also provides information about the determinism and stability of synchrony. As means and variances of the data change over time, standard statistics based on those means and variances cannot help us understand the changing pattern of synchrony. Determinism and stability indicate the extent to which the changes in our data are driven by the elements of the system rather than by unknown external agents, and the ease with which synchrony could be interrupted. In the real world of strategic communication, we want to build messages whose influences on people are similar across people (synchronous), resistant to external perturbations (stable) and driven solely by the message itself (deterministic). This study suggests that negative arousing compared to positive arousing messages and calm compared to arousing messages are more likely to elicit more stable and less random-process-involved synchrony across individuals. For instance, when we want to use media to bring people together, designing messages high in those traits are more likely to enhance the sense of cohesion.

The study has some limitations. First, the large number of female participants (77.78% of the sample) may lead to stronger SCL synchrony in general. Research shows that women are more sensitive to environmental cues (Donges et al., 2012). Future studies might want to balance gender and test for gender effects on SCL synchrony. Second, participants in this study were highly homogenous regarding their responses toward the stimuli. Most of them had strong identity with their home university's basketball team. This might be another reason that led to such a strong synchrony for both dyads of friends and strangers. Future studies may want to test how dyads' differences in individual personality and basketball knowledge could affect SCL synchrony in this television viewing context. Future research could also test the relationship between attention and SCL synchrony. A more attentive state might bring less randomness to the system and thus give rise to a stronger and more stable synchronization. For example, future research could examine the synchrony on a moment-to-moment basis and whether synchrony is stronger during periods of high attentiveness. The examination of the attention-and-synchrony relationship will deepen our understanding of physiological and neurological synchrony during media viewing.

Psychological similarity is critical for human survival, social interaction, and interpersonal understanding. Our study suggests that media not only make people think alike but also feel alike, such that media synchronize audiences both cognitively *and emotionally*. Research has shown that interpersonal synchronization coordinates people's thoughts and behaviors, increases people's understanding and liking for one another as well as increasing their sense of similarity, rapport, and affiliation (Lakin & Chartrand, 2003; Rabinowitch & Knafo-Noam, 2015). As media synchronize viewers cognitively and emotionally, people exposed to the same media content might better understand one another. This mutual understanding is not only the result of having the same knowledge, but more importantly, our study shows that, it is the result of experiencing the same emotions through media.

References

Abarbanel, H.D.I. (1996). *Analysis of observed chaotic data*. Springer.

Aiken, L.S. & West, S.G. (1991). *Multiple regression: Testing and interpretting interactions.* Sage.

Bates. D,. (2010, June 25). *Lme4: Mixed-effects modeling with R*. https://lme4.r-forge.r-project.org/book/

Bertenthal, B. I. (2007). Dynamical systems: It's about time. In Boker SM, Wenger MJ (eds), *Data analytic techniques for dynamical systems* (pp. 1–24). Lawrence Erlbaum Associates.

Bower, G. H. (1981). Mood and memory. *American Psychologist*, *36*(2), 129-148. https://doi.org/10.1037/0003-066X.36.2.129

Bradley, M. M., Codispoti, M., Cuthbert, B. N., & Lang, P. J. (2001). Emotion and motivation I: Defensive and appetitive reactions in picture processing. *Emotion*, *1*(3), 276–298. https://doi.org/10.1037/1528-3542.1.3.276

Bradley, M. M., Codispoti, M., Sabatinelli, D., & Lang, P. J. (2001). Emotion and motivation II: Sex differences in picture processing. *Emotion*, *1*(3), 300–319. https://doi.org/10.1037/1528-3542.1.3.300

Bradley, M.M., & Lang, P. (2000). Measuring emotion: behavior, feeling, and physiology. In R.D. Lane and L. Nadel (eds), *Cognitive neuroscience of emotion* (pp. 242-276). Oxford University Press.

Braithwaite, J., Watson, D., Jones, R., & Rowe, M. (2013). A guide for analysing electrodermal activity (EDA) & skin conductance responses (SCRs) for psychological experiments. Biopac. https://www.biopac.com/wp-content/uploads/guide-electrodermal-activity.pdf.

Butler, E. A. (2011). Temporal interpersonal emotion systems: The "TIES" that form relationships. *Personality and Social Psychology Review*, *15*(4), 367–393. https://doi.org/10.1177/1088868311411164

Cacioppo, J. T., & Berntson, G. G. (1994). Relationship between attitudes and evaluative space: A critical review, with emphasis on the separability of positive and negative substrates. *Psychological Bulletin*, *115*(3), 401–423. https://doi.org/10.1037/0033-2909.115.3.401

Choi, D., Conture, E. G., Walden, T. A., Jones, R. M., & Kim, H. (2016). Emotional diathesis, emotional stress, and childhood stuttering. *Journal of Speech, Language, and Hearing Research*, *59*(4), 616-630. https://doi.org/10.1044/2015_JSLHR-S-14-0357

Coco, M. I., & Dale, R. (2014). Cross-recurrence quantification analysis of categorical and continuous time series: an R package. *Frontiers in psychology*, *5*, 510. https://doi.org/10.3389/fpsyg.2014.00510

Creaven, A. M., Skowron, E. A., Hughes, B. M., Howard, S., & Loken, E. (2014). Dyadic concordance in mother and preschooler resting cardiovascular function varies by risk status. *Developmental Psychobiology*, *56*(1), 142–152. https://doi.org/10.1002/dev.21098

Dawson, M. E., Schell, A. M., & Filion, D. L. (2007). The electrodermal system. In J. T. Cacioppo, L. G. Tassinary, & G. Berntson (Eds.), *Handbook of psychophysiology* (pp. 159–181). Cambridge University Press.

Donges, U. S., Kersting, A., & Suslow, T. (2012). Women's greater ability to perceive happy facial emotion automatically: Gender differences in affective priming. *PLoS ONE*, *7*(7), 1–6. https://doi.org/10.1371/journal.pone.0041745

Findlay, F. (2016). How to get great electrodermal activity (EDA) data. Biopac. https://www.biopac.com/wp-content/uploads/How-to-get-Great-EDA-Data-US-%E2%80%93-webinar-slides.pdf

Fredrickson, B. L. (2001). The role of positive emotions in positive psychology: The broaden-and-build theory of positive emotions. *American Psychologist, 56*(3), 218–226. https://doi.org/10.1037/0003-066X.56.3.218

Gerbner, G., Gross, L., Morgan, M., & Signorielli, N. (1980). The "mainstreaming" of America: violence profile number 11. *Journal of Communication, 30*(3), 10–29. https://doi.org/10.1111/j.1460-2466.1980.tb01987.x

Golland, Y., Keissar, K., & Levit-Binnun, N. (2014). Studying the dynamics of autonomic activity during emotional experience. *Psychophysiology*, *51*(11), 1–11. https://doi.org/10.1111/psyp.12261

Han, J. (2020). Physiological and emotional synchrony during television viewing: A nonlinear dynamic systems approach (Publication No. 28002093) [Doctoral dissertation, Indiana University]. ProQuest Dissertations Publishing.

Hatfield, E., Cacioppo, J. T., & Rapson, R. L. (1993). Emotional contagion. *Current Directions in Psychological Science*, *2*(3), 96-100. https://doi.org/10.1111/1467-8721.ep10770953

Hasson, U., Nir, Y., Levy, I., Fuhrmann, G., Malach, R. (2004). Intersubject Synchronization of Cortical Activity During Natural Vision. *Science*, *303*(5664), 1634–1640. https://doi.org/10.1126/science.1089506

Hasson, U., & Frith, C. D. (2016). Mirroring and beyond: coupled dynamics as a generalized framework for modelling social interactions. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *371*(1693), 20150366. https://doi.org/10.1098/rstb.2015.0366

Hasson, U., Malach, R., & Heeger, D. J. (2010). Reliability of cortical activity during natural stimulation. *Trends in Cognitive Sciences, 14*(1), 40–48. DOI: 10.1016/j.tics.2009.10.011

Kay, B. & Richardson, M. J. (2015). Recurrence quantification analysis conducting using MATLAB code for the APA Advanced Institute of Nonlinear methods for Psychology Science. https://github.com/xkiwilabs.

Lakin, J. L., & Chartrand, T. L. (2003). Using nonconscious behavioral mimicry to create affiliation and rapport. *Psychological Science*, *14*(4), 334–339. https://doi.org/10.1111/1467-9280.14481

Lang, A. (2006). Using the limited capacity model of motivated mediated message processing to design effective cancer communication messages. *Journal of Communication*, *56*, S57–S80. https://doi.org/10.1111/j.1460-2466.2006.00283.x

Lang, A. (2014). Dynamic human-centered communication systems theory. *Information Society*, *30*(1), 60–70. https://doi.org/10.1080/01972243.2013.856364

Lang, A., Park, B., Sanders-Jackson, A. N., Wilson, B. D., & Wang, Z. (2007). Cognition and emotion in TV message processing: How valence, arousing content, structural complexity, and information density affect the availability of cognitive resources. *Media Psychology*, *10*(3), 317-338. https://doi.org/10.1080/15213260701532880

Lang, A., Sanders-Jackson, A., Wang, Z., & Rubenking, B. (2013). Motivated message processing: How motivational activation influences resource allocation, encoding, and storage of TV messages. *Motivation and Emotion*, *37*(3), 508–517. https://doi.org/10.1007/s11031-012-9329-y

Lang, A., Shin, M., & Lee, S. (2005). Sensation seeking, motivation, and substance use: A dual system approach. *Media Psychology, 7*(1), 1–29. https://doi.org/10.1207/S1532785XMEP0701_1

Lang, A., Zhou, S., Schwartz, N., Bolls, P. D., & Potter, R. F. (2000). The effects of edits on arousal, attention, and memory for television messages: When an edit is an edit can an edit be too much?. *Journal of Broadcasting & Electronic Media*, *44*(1), 94-109. https://doi.org/10.1207/s15506878jobem4401_7

Lee, M. K. (2019, September). Cognitive and emotional processing of TV commercials in mediated sports: A re-inquiry using a psycho-physiological approach. Paper was presented at the 27th Conference of the European Association for Sport Management (EASM). Seville, UK.

Marwan, N., Romano, M. C., Thiel, M., Kurths, J. (2007). Recurrence plots for the analysis of complex systems, *Physics Reports, 438(5-6), 237-329, 2007*. https://doi.org/10.1016/j.physrep.2006.11.001

McCombs, M. E., & Shaw, D. L. (1972). The agenda-setting function of mass media. *Public Opinion Quarterly*, *36*(2), 176–187. https://doi.org/10.1086/267990

McCombs, M., Llamas, J. P., Lopez-Escobar, E., & Rey, F. (1997). Candidate images in Spanish elections: Second-level agenda-setting effects. *Journalism & Mass Communication Quarterly*, *74*(4), 703–717. https://doi.org/10.1177/107769909707400404

Nakano, T., Yamamoto, Y., Kitajo, K., Takahashi, T., & Kitazawa, S. (2009). Synchronization of spontaneous eyeblinks while viewing video stories. *Proceedings of the Royal Society B: Biological Sciences*, *276*(1673), 3635–3644. https://doi.org/10.1098/rspb.2009.0828

Nummenmaa, L., Glerean, E., Viinikainen, M., Jaaskelainen, I. P., Hari, R., & Sams, M. (2012). Emotions promote social interaction by synchronizing brain activity across individuals. *Proceedings of the National Academy of Sciences*, *109*(24), 9599–9604. https://doi.org/10.1073/pnas.1206095109

Page-Gould, E. (2017). Multilevel modeling. In J. T. Cacioppo, L. G. Tassinary, & G. G.

Berntson (Eds.), *Handbook of psychophysiology* (p. 662–678). Cambridge University Press.

Parkinson, C., Kleinbaum, A. M., & Wheatley, T. (2018). Similar neural responses predict friendship. *Nature Communications*, *9*(1), 1–14. https://doi.org/10.1038/s41467-017-02722-7

Pettersson, E., Boker, S. M., Watson, D., Clark, L. A., & Tellegen, A. (2013). Modeling daily variation in the affective circumplex: A dynamical systems approach. *Journal of Research in Personality*, *47*(1), 57-69. https://doi.org/10.1016/j.jrp.2012.10.003

Potter, R. F., & Bolls, P. (2012). *Psychophysiological measurement and meaning: Cognitive and emotional processing of media*. Routledge.

Potter, R. F., Lang, A., & Bolls, P. D. (2008). Identifying structural features of audio: Orienting responses during radio messages and their impact on recognition. *Journal of Media Psychology*, *20*(4), 168–177. https://doi.org/10.1027/1864-1105.20.4.168

Rabinowitch, T. C., & Knafo-Noam, A. (2015). Synchronous rhythmic interaction enhances children's perceived similarity and closeness towards each other. *PLoS ONE*, *10*(4), e0120878. https://doi.org/10.1371/journal.pone.0120878

Richardson, M. J., Schmidt, R. C., & Kay, B. A. (2007). Distinguishing the noise and attractor strength of coordinated limb movements using recurrence analysis. *Biological Cybernetics*, *96*(1), 59–78. https://doi.org/10.1007/s00422-006-0104-6

Richardson, M. J., Dale, R., & Marsh, K. L. (2014). Complex dynamical systems in social and personality psychology. In H. T. Reis and C. M. Judd (Eds.) *Handbook of research methods in social and personality psychology* (pp. 253–282). Cambridge University Press.

Riley, M. A., & Turvey, M. T. (2002). Variability and determinism in motor behavior. *Journal of Motor Behavior*, *34*(2), 99-125. https://doi.org/10.1080/00222890209601934

Strogatz, S. H. (1994). *Nonlinear dynamics and chaos: with applications to physics, biology, chemistry, and engineering*. Perseus Books Group.

Schoenewolf, G. (1990). Emotional contagion: Behavioral induction in individuals and groups. *Modern Psychoanalysis*, *15*(1), 49–61.

Shockley, K. (2005). Cross recurrence quantification of interpersonal postural activity. In M. A. Riley & G. C. Van Orden (Eds.), *Tutorials in contemporary nonlinear methods for the behavioral sciences* (pp. 142-177). *National science foundation*. http://www.nsf.gov/sbe/bcs/pac/nmbs/nmbs.jsp

Takens, F. (1981). Detecting strange attractors in turbulence. *Lecture notes in mathematics*, *898*(1), 366-381.

Wang, Z., & Lang, A. (2012). Reconceptualizing excitation transfer as motivational activation changes and a test of the television program context effects. *Media Psychology*, *15*(1), 68–92. https://doi.org/10.1080/15213269.2011.649604

Webber, C. L., & Zbilut, J. P. (2005). Recurrence quantification analysis of nonlinear dynamical systems. In M. A. Riley & G. C. Van Orden (Eds.), *Tutorials in contemporary nonlinear methods for the behavioral science* (pp. 26-94). *National science foundation*. http://www.nsf.gov/sbe/bcs/pac/nmbs/nmbs.jsp

Webber, C. L. & Marwan, N., (Eds.). (2015). *Recurrence quantification analysis: Theory and best practices*. Springer.

Weber, R., Eden, A., Huskey, R., Mangus, J. M., & Falk, E. (2015). Bridging media psychology and cognitive neuroscience: Challenges and opportunities. *Journal of Media Psychology, 27*(3), 146–156. https://doi.org/10.1027/1864-1105/a000163

Weber, R., Tamborini, R., Westcott-Baker, A., & Kantor, B. (2009). Theorizing flow and media enjoyment as cognitive synchronization of attentional and reward networks. *Communication Theory*, *19*(4), 397–422. https://doi.org/10.1111/j.1468-2885.2009.01352.x

Wild, B., Erb, M., & Bartels, M. (2001). Are emotions contagious? Evoked emotions while viewing emotionally expressive faces: Quality, quantity, time course and gender differences. *Psychiatry Research*, *102*(2), 109–124. https://doi.org/10.1016/S0165-1781(01)00225-6

Yang, T., Majó-Vázquez, S., Nielsen, R. K., & González-Bailón, S. (2020). Exposure to news grows less fragmented with an increase in mobile access. *Proceedings of the National Academy of Sciences*, *117*(46), 28678-28683. https://doi.org/10.1073/pnas.2006089117

Zengin-Bolatkale, H., Conture, E. G., Walden, T. A., & Jones, R. M. (2018). Sympathetic arousal as a marker of chronicity in childhood stuttering. *Developmental neuropsychology*, *43*(2), 135-151. https://doi.org/10.1080/87565641.2018.1432621

Zillmann, D. (1971). Excitation transfer in communication-mediated aggressive behavior. *Journal of Experimental Social Psychology*, *7*(4), 419-434. https://doi.org/10.1016/0022-1031(71)90075-8

Table 1 *MLM Results with the Transformed Recurrence Quantifications*

	logit.REC		**logit.DET**		**sqrt.MAXLINE**	
Predictors	*Estimates*	*CI*	*Estimates*	*CI*	*Estimates*	*CI*
(Intercept)	-3.10 ***	-3.39 – -2.80	3.20 ***	2.55 – 3.85	5.65 ***	4.77 – 6.53
Arousal [Calm]	0.59 ***	0.46 – 0.71	1.17 ***	0.98 – 1.36	1.55 ***	1.24 – 1.86
Valence [Positive]	-0.37 ***	-0.50 – -0.24	-0.37 ***	-0.56 – -0.18	-0.80 ***	-1.11 – -0.49
Emotional Change Rate [Slow Changing]	-0.50 *	-0.89 – -0.11	-0.79	-1.65 – 0.08	-0.83	-2.00 – 0.35
Arousal [Calm] * Valence[Positive]	-0.00	-0.18 – 0.18	-0.59 ***	-0.86 – -0.32	-0.13	-0.57 – 0.31
Arousal [Calm] * Emotional Change Rate [Slow Changing]	-0.24 **	-0.40 – -0.07	-0.80 ***	-1.04 – -0.56	-0.68 ***	-1.08 – -0.29
Valence [Positive] * Emotional Change Rate [Slow Changing]	-0.01	-0.17 – 0.15	-0.11	-0.35 – 0.13	0.02	-0.37 – 0.42
(Arousal [Calm] * Valence [Positive]) * Emotional Change Rate [Slow Changing]	0.79 ***	0.56 – 1.02	1.92 ***	1.58 – 2.27	1.85 ***	1.29 – 2.41
Random Effects						
σ^2	0.79		1.76		4.79	
τ_{00}	0.16 $_{\text{DyadMember1}}$		0.79 $_{\text{DyadMember1}}$		1.05 $_{\text{DyadMember1}}$	
	0.21 $_{\text{DyadMember2}}$		1.16 $_{\text{DyadMember2}}$		2.44 $_{\text{DyadMember2}}$	
ICC	0.32		0.53		0.42	
Marginal R^2 / Conditional R^2	0.15 / 0.42		0.12 / 0.58		0.11 / 0.48	

Note. * *p<0.05* ** *p<0.01* *** *p<0.001*. Beta values are unstandardized because the independent variables are all categorical. *F* statistics of the three-way interaction effect: (1) logit. REC: *F* (1, 3770.1) = 45.23, *p* < .001; (2) logit. DET: *F* (1, 3780.7) = 120.55, *p* < .001; (3) sqrt. *MAXLINE: F* (1, 3810.6) = 41.45, *p* < .001.

Table 2

Results of Post-hoc Simple Effect Tests

	Logit.%REC		Logit.%DET		Sqrt.MaxLine	
	B (*SE*)	*t*	*B* (*SE*)	*t*	*B* (*SE*)	*t*
Message Valence Effect						
Calm + Slow changing	.41(.05)	7.93***	.86(.08)	11.08***	.94(.12)	7.41***
Calm + Fast changing	-.37(.06)	-5.76***	-.96(.10)	-9.91***	-.93(.16)	-5.86***
Arousing + Slow changing	-.38(.05)	-7.34***	-.47(.08)	-6.15***	-.78(.13)	-6.16***
Arousing + Fast changing	-.37(.07)	-5.68***	-.37(.10)	-3.78***	-.80(.16)	-5.06***
Message Arousal Effect						
Positive + Slow changing	1.14(.05)	21.95***	1.70(.08)	21.96***	2.58(.13)	20.37***
Positive + Fast changing	.59(.07)	8.90***	.58(.10)	5.96***	1.42(.16)	8.91***
Negative + Slow changing	.35(.05)	6.84***	.37(.08)	4.80***	.86(.13)	6.82***
Negative + Fast changing	.59(.06)	9.08***	1.17(.10)	12.10***	1.55(.16)	9.75***
EmotionalChangeRate Effect						
Negative + Calm	-.74(.02)	-3.69***	-1.59(.44)	-3.58***	-1.51(60)	-2.51*
Negative + Arousing	-.50(.02)	-2.51*	-.79(.44)	-1.77	-.83(.60)	-1.37
Positive + Calm	.41(.02)	.21	.22(.44)	.51	.37(.60)	.61
Positive + Arousing	-.51(.02)	-2.55*	-.89(.44)	-2.02*	-.80(.60)	-1.33

Note. *** $p < .001$, ** $p < .01$, * $p < .05$. The Aiken and West's simple slope testing was used for post hoc analyses (Aiken & West, 1991; Page-Gould, 2017). Results were tested on transformed %REC and %DET using the logit transformation and on transformed MaxLine using the square root transformation. Same as Table 1, beta values are unstandardized.