Biological Psychology 129 (2017) 73–81

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

Research paper

The effect of visual and musical suspense on brain activation and memory during naturalistic viewing

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ARTICLE INFO

Keywords:
Attention
Emotion
Music
Narrative transportation
Suspense

ABSTRACT

We tested the hypothesis that, during naturalistic viewing, moments of increasing narrative suspense narrow the scope of attentional focus. We also tested how changes in the emotional congruency of the music would affect brain responses to suspense, as well as subsequent memory for narrative events. In our study, participants viewed suspenseful film excerpts while brain activation was measured with functional magnetic resonance imaging. Results indicated that suspense produced a pattern of activation consistent with the attention-narrowing hypothesis. For example, we observed decreased activation in the anterior calcarine sulcus, which processes the visual periphery, and increased activity in nodes of the ventral attention network and decreased activity in nodes of the default mode network. Memory recall was more accurate for high suspense than low suspense moments, but did not differ by soundtrack congruency. These findings provide neural evidence that perceptual, attentional, and memory processes respond to suspense on a moment-by-moment basis.

1. Introduction

The theory of narrative transportation postulates psychological activities that occur as people experience narrative worlds (Gerrig, 1993; Green and Brock, 2000). A key claim of the theory is that narratives can focus a viewer's perception and attention on the actions and concerns of characters while attenuating attention to the external environment of the viewer. Past research has found evidence to support this claim in behavioral research (Bezdek and Gerrig, 2017; Bezdek et al., 2015). Narrative transportation is also postulated to have consequences on processes beyond perception and attention, including increased encoding of narrative-consistent knowledge and attitudes (Gerrig, 1993; Green and Brock, 2000; Murphy, Frank, Moran, & Patnoe-Woodley, 2011). Our previous reports (Bezdek and Gerrig, 2017; Bezdek et al., 2015) produced insignificant trends supporting this claim.

In the present study, we tested the attentional narrowing hypothesis by measuring activity in visual and attentional brain networks evoked by suspenseful feature films during naturalistic viewing. Films are useful for studying psychological processes like attention and emotion because they reliably evoke responses across participants on a common timescale (Smith, Levin, & Cutting, 2012). In particular, professional films evoke a high degree of synchrony across viewers, in terms of both eye movements (Mital, Smith, Hill, & Henderson, 2011; Smith and Henderson, 2008; Wang, Freeman, Merriam, Hasson, & Heeger, 2012) and in evoked brain responses (Dmochowski et al., 2014; Dmochowski, Sajda, Dias, & Parra, 2012; Hasson, Malach, & Heeger, 2010; Hasson, Nir, Levy, Fuhrmann, & Malach, 2004). Though a systematic comparison of film genres has not been performed, researchers have reported that a suspenseful program directed by Alfred Hitchcock elicited a particularly high degree of synchrony across cerebral cortex (Hasson, Landesman, Knappmeyer, Vallines, Rubin, & Heeger, 2008) and has been used to compare attention across age groups (Campbell et al., 2015), as well as test for consciousness (Naci, Cusack, Anello, & Owen, 2014).

In previous behavioral and neuroimaging research, we found evidence that suspense narrows the scope of attentional focus. When performing a secondary reaction time task to auditory probes while viewing suspenseful film excerpts, participants were slower to respond, and missed more probes, when suspense was high than when suspense was low (Bezdek and Gerrig, 2017). We also found neuroimaging evidence of attentional narrowing at suspenseful time points (Bezdek et al., 2015). In an MRI scanner, participants fixated on suspenseful film excerpts at the center of a screen, and checkerboards continuously flashed in the periphery. We found that moments of increasing suspense suppressed processing of the peripheral checkerboards, relative to moments of decreasing suspense. In contrast, suspense evoked increased activation in areas of primary visual cortex that represent the fovea. Suspense also evoked increased activation in the right inferior frontal

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http://dx.doi.org/10.1016/j.biopsycho.2017.07.020
Received 5 May 2016; Received in revised form 21 June 2017; Accepted 25 July 2017
Available online 29 July 2017
0301-0511/

and temporoparietal cortices and decreased activation in the posterior cingulate and lateral temporal cortices. Functionally, the right inferior frontal and temporoparietal cortices are components of the ventral attention network, implicated in stimulus-driven attention (Corbetta, Patel, & Shulman, 2008). The posterior cingulate and lateral temporal cortices are components of the default-mode network, implicated in inwardly focused attention (Buckner et al., 2008). We hypothesized that this increased perceptual and attentional processing could lead to downstream consequences such as enhanced memory encoding, a claim we tested in the present study. In the present study, we investigated brain activation using a procedure that more closely mirrored the way in which people regularly view films and experience everyday life. This technique allowed us to directly test the attentional narrowing hypothesis of suspense in visual and attention brain regions under naturalistic viewing conditions.

Given the robust attentional narrowing effect of suspense, the present research investigated the potential downstream consequences of this narrative suspense. Past work has found that attention at encoding impacts later memory performance (Chun and Turk-Browne, 2007; Uncapher and Rugg, 2009). From these findings, we theorized that the attentional focusing effect of suspense might enhance the encoding of content at suspenseful moments over other time points in the narrative. However, in our own previous work, we found only weak evidence that participants encode and recall content more accurately at moments of increasing suspense. Participants did not show significantly better memory for the colors of objects at suspenseful time points (Bezdek et al., 2015), and memory for the orientation or presence of film stills at suspenseful moments was no better following suspenseful scene viewing than following presentation of shuffled still images (Bezdek and Gerrig, 2017).

A potential reason for the weak effects in our previous studies may be that surface details like color and the placement of objects in films are not encoded into long-term memory − even with increased attention. For example, participants fail to notice dramatic changes in these features (e.g., a green shirt changes to blue) across cuts (Levin and Simons, 1997). Instead, viewers tend to focus on the actions and goals of the film characters (Bordwell, 2013). It is possible that narrative transportation would enhance memory for events related to the narrative rather than surface content. Consistent with this idea, in one study with a test of long-term memory for film content, recall performance was best for questions related to plot themes and social interactions, rather than specific details or jokes (Furman, Dorfman, Hasson, Davachi, & Dudai, 2007). In the present study, we predicted that participants would demonstrate better recall of narrative events from high suspense rather than low suspense moments.

In addition to testing memory and brain activation responses to narrative suspense, we also manipulated the musical soundtrack associated with each film. Film music has the power to influence the emotions expressed and evoked by the narrative content. Psychologists have tested the influence of emotional film music by pairing the same film excerpt with soundtracks that express varied emotions. This procedure has revealed that music can influence judgments of the emotions and intentions of film characters (Bullerjahn and Güldenring, 1994; Marshall and Cohen, 1988; Tan, Spackman, & Bezdek, 2007), predictions of what will occur next (Vitouch, 2001), and memory encoding of film content (Boltz, Schulkind, & Kantra, 1991; Boltz, 2004). Despite these diverse effects, film music can at times elude the conscious perception of the viewer, whose primary motivation is often following the goals and actions of characters. We examined how manipulating film music influences ratings of suspense and alters patterns of neural activation measured with fMRI.

2. The present study

In the present study, we tested the effect of suspense during relatively naturalistic viewing on activation of visual and attentional brain networks. Participants viewed suspenseful film excerpts that filled the entire screen, and participants were instructed to freely view the film excerpts, as they would normally watch a movie. We manipulated the accompanying soundtracks to the film excerpts, so that each excerpt could be accompanied by congruent (suspenseful) music, incongruent (happy/calm) music, or no music. Following the scan session, we administered a recall test for the narrative content of the film excerpts. We predicted that recall performance would be better for moments of high rather than low suspense.

3. Method

3.1. Participants

Twenty-one undergraduates of the Georgia Institute of Technology (6 female, age range 18–25) participated in the study. All participants were right-handed, native English speakers, with normal or corrected-to-normal vision. Of these 21 participants, one was excluded from fMRI analyses due to a technical error in stimulus presentation that prevented time-syncing with the scanner. This error did not affect the recall test, so recall data from all 21 participants was included in these analyses. All participants provided informed consent and received course credit or payment for participation in accordance with the procedure approved by the Georgia Institute of Technology IRB.

3.2. Stimuli

A series of nine suspenseful excerpts were selected from commercial motion pictures (average duration = 3.00 min). In each excerpt, a character faced the threat of a potential negative outcome. All excerpts contained suspenseful visual sequences with no dialogue, though 7 of the 9 excerpts contained moments of dialogue. Excerpts were edited to be self-contained episodes of approximately the same duration, with no music in their original versions. Two additional versions of each film excerpt were created using the program Final Cut Pro, with music excerpts drawn from other commercial films. These excerpts were judged by the first author to express emotional moods either congruent or incongruent with the suspenseful mood of the visual narrative on the basis of the following musical features. One version contained film music congruent with the suspenseful scene, with changes in amplitude, minor key structures, and high dissonance. The other version contained incongruent music of a happy or calm mood, with fewer changes in amplitude, major key structures, and high consonance. See Table 1 for a summary of all film and music selections. To validate these music choices, four lab personnel heard all excerpts in a random order and rated each for both suspenseful and happy/calm emotional expression, on a scale from 1 to 9. These ratings confirmed the accuracy of the selections (congruent excerpts: suspenseful $M = 7.39$, happy/calm $M = 2.08$; incongruent excerpts: suspenseful $M = 1.92$, happy/calm $M = 7.83$). Audio volume was normalized for each version of each excerpt. All music excerpts were trimmed to fit the film excerpts, but no effort was made to synchronize visual and musical accents. Three sets of the nine film excerpts were randomly generated, with a third of each music type (3 congruent, 3 incongruent, 3 no music). Video files of the stimuli used in this study are available by request from the first author.

3.3. Suspense norming experiment

A set of 20 undergraduates (13 female) at Stony Brook University, who did not take part in the fMRI experiment, completed a behavioral experiment to generate suspense ratings for all versions of the film excerpts. All participants were native English speakers. Participants sat at a computer and moved a slider to indicate how strongly potential threats to the characters were emphasized by the current narrative content. Participants viewed all excerpts of just one soundtrack type (congruent, incongruent, no music), presented in a randomized order.

Table 1
Sources for Film and Music Excerpts Used in the Study.

Film Source (Director, Year)	Excerpt Onset	Excerpt Duration	Congruent Music	Incongruent Music
Bang! You're Dead (Alfred Hitchcock, 1961)	0:08:04	3:14	"The Forest" by Bernard Herrmann from *Vertigo*	"Incontro Magico II" by Ennio Morricone from *Slalom*
Blood Simple (Joel Coen, 1984)	1:21:56	2:39	"The Dead Zone" by Michael Kamen from *The Dead Zone*	"Profound Loss" by James Horner from *The Missing*
The Day Of The Jackal (Fred Zinnemann, 1973)	2:13:52	2:35	"Closing In On Ray" by John Barry from *The Specialist*	"Charley Rides Off" by Michael Kamen from *Open Range*
Dog Day Afternoon (Sidney Lumet, 1975)	1:53:07	3:12	"Opening The Casket" by James Horner from *Flight Plan*	"Growing Old" by James Horner from *Bicentennial Man*
Julia (Erick Zonca, 2008)	0:38:58	2:49	"Twenty-Three And One Half Hours A Day" by Mark Isham from *Last Dance*	"The Wedding" by James Horner from *Legends Of The Fall*
Marnie (Alfred Hitchcock, 1964)	0:45:44	3:04	"La Gelosia Di Simone" by Nino Rota from *Rocco E I Suoi Fratelli*	"New Baby/Coltrane/Children Should Listen To Mozart" by Michael Kamen from *Mr. Holland's Opus*
Munich (Steven Spielberg, 2005)	0:47:45	2:51	"The Chasm And The Valley" by Bernard Herrmann from *Garden of Evil*	"At Last" by Alan Silvestri from *Maid In Manhattan*
North By Northwest (Alfred Hitchcock, 1959)	1:11:16	3:15	"Circus Nocturne" by Franz Reizenstein and Muir Mathieson from *Circus Of Horrors*	"Toby's Theme" by Howard Shore from *Nobody's Fool*
Saboteur (Alfred Hitchcock, 1942)	1:44:43	3:17	"Terror On The Ski Run" by Miklós Rózsa from *Spellbound*	"Scherzo" by Miklós Rózsa from *Spellbound*

For each music type version of each excerpt, the time courses were averaged across all participants who viewed the specific soundtrack version. This procedure was used in previous research to generate suspense time courses that were used as regressors in an fMRI experiment to model the brain response to suspense (Bezdek et al., 2015).

3.4. Procedure

After providing written consent, participants began the scanning session. Participants were randomly assigned to view one of the three sets of all nine excerpts, which they viewed in an individually randomized order while functional volumes were acquired. Stimuli were projected onto a screen located behind the MRI scanner, which participants viewed through a mirror connected to the head coil. The excerpts filled the screen, and participants were instructed to watch them as they would normally watch a film. Before each excerpt, the experimenter read aloud a paragraph that introduced the characters and scenario. Each excerpt was also preceded and followed by 20 s of a fixation cross on a black background. After viewing all excerpts, we acquired an anatomical MPRAGE sequence. Then, participants viewed and rated a series of advertisements. This task was unrelated to the current study, and its results are reported elsewhere (Dmochowski et al., 2014).

After completing the scanning session, participants went to another room to complete a surprise recall test for film content. Participants answered 81 free response questions, one for the narrative content of each 20 s of film time (for example, Q: What happens as Marie is walking to the stairwell? A: One of her shoes falls to the ground and makes a loud noise). The test was administered using E-Prime software. We debriefed participants after the recall test. Participants indicated if they had previously viewed any of the film excerpts and if they were aware of any manipulation to the film excerpts.

3.5. Imaging parameters

MRI acquisition was performed with a 3T Siemens Magnetom Trio scanner with a 12-channel head coil. Functional whole-brain volumes were collected using an echo-planar imaging sequence, with separate runs for each film excerpt and these parameters: TR = 2000 ms, TE = 30 ms, flip angle = 90°, acquisition matrix = 68 × 68, 3 mm isotropic voxels, 37 slices, gap = 17%. The structural scan used the following parameters: TE = 3.98 ms; TR = 2250 ms; flip angle = 9°; acquisition matrix = 256 × 256; 1 mm isotropic voxels, 176 slices.

3.6. fMRI analyses

MRI data were preprocessed using tools from Analysis of Functional Neuroimages software (AFNI; http://afni.nimh.nih.gov/afni) and the FMRIB Software Library (FSL; http://www.fmrib.ox.ac.uk). We corrected slice timing, then head motion with six parameters. Next, spatial smoothing was performed with a 6 mm full width at half maximum Gaussian kernel. Volumes were then transformed to standardized space with the template of the Montreal Neurological Institute and high-pass filtered with a frequency cut-off of 0.0078 Hz using linear regression.

To probe the effect of increasing suspense, we performed a general linear model (GLM) analysis using changes in suspense as a regressor of interest. The derivative function of the average slider suspense ratings for each music type was converted to a z-score, convolved with the canonical hemodynamic response function, and then downsampled to the timescale of fMRI acquisition (TR = 2 s). The design matrix also included regressors for boxcar functions of film viewing time for each soundtrack type, constant, linear, and quadratic trends for each run, head movement with six parameters, and regressors based low-level visual properties of the films (hue, saturation, luminance, edges, and optical flow). Each of these low-level properties was averaged per frame of each video, converted to a z-score, convolved with a canonical hemodynamic response function, and downsampled to the TR rate. The β-values from each voxel in the individual regression analyses were submitted to a second-level ANOVA with music (congruent, incongruent, none) as a fixed factor and subject as a random factor. The resulting statistics were thresholded at a corrected voxel-wise false discovery rate (FDR) of $p < 0.05$. In addition to FDR correction, a minimum cluster size of 50 voxels was applied to make the tables and figures clearer. Planned contrasts between the three soundtrack types were also performed. To determine common activation across soundtrack conditions, a conjunction analysis was performed. The statistical parametric maps of each music type were overlaid to display voxels significant for all three conditions. To compare differences in activation across general film viewing across the three soundtrack types, an ANOVA was also performed on the boxcar functions for the three soundtrack types. The same statistical thresholds were used for this analysis as for the suspense analysis.

4. Results

4.1. Suspense norming experiment

The average time courses of suspense for each film are displayed in Fig. 1A. A repeated measures ANOVA on the average suspense rating across film excerpts (Fig. 1B) revealed a significant effect of music congruency, $F(2,8) = 122.64$, $p < 0.001$, partial $\eta^2 = .98$. Follow-up paired t-tests confirmed that the average level of suspense was different between each type of music: congruent music was rated as higher suspense than incongruent ($t(8) = 9.19$, $p < 0.001$, Cohen's $d = 3.16$) or no music ($t(8) = 19.89$, $p < 0.001$, Cohen's $d = 6.62$), and incongruent music was rated as higher suspense than no music ($t(8) = 5.69$, $p < 0.001$, Cohen's $d = 1.93$). These differences are statistically significant at a Bonferroni-corrected α of 0.016 for the three comparisons.

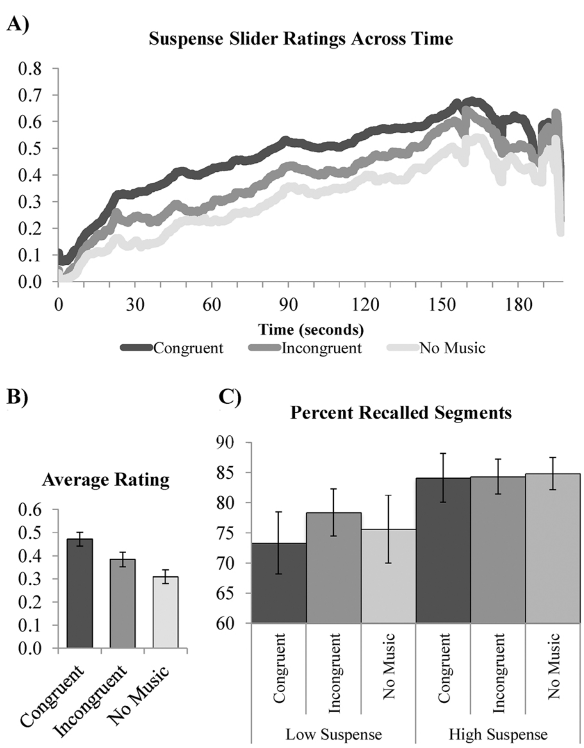

Fig. 1. A) Slider suspense rating by film music type. The time course for each film for each music type is plotted and the average time courses for each music type are displayed in bold. Scores were recorded on a linear scale from 0.0 to 1.0. On average, congruent music produced higher suspense ratings than incongruent or no music, though there is variation in the individual time courses for each film. B) Slider suspense ratings averaged across time. Incongruent music evoked higher average ratings than no music and congruent music evoked higher ratings than incongruent music. C) Average recall performance by level of suspense (low or high) and music accompaniment version (congruent, incongruent, or no music).

4.2. Memory recall test performance

Recall test responses were scored by two independent raters who judged if each response sufficiently matched a predetermined correct answer. Any disagreements between the raters were resolved through discussion. Agreement was high (92%, *Cohen's Kappa* = 0.77), confirming the validity of the scoring procedure. Following scoring, the questions were divided with a median split for the average level of visual suspense (for the no music version of each film excerpt) over the 20 s duration corresponding to each question. This resulted in 40 high suspense items and 40 low suspense items. For each participant, items were further divided by the type of music that accompanied the film excerpt (congruent, incongruent, or none). Participant accuracy scores were then included in a 2 (suspense) x 3 (music type) repeated measures ANOVA. This analysis revealed a significant main effect of visual suspense ($F(1,20) = 12.99$, $p < 0.005$, partial $\eta^2 = .394$), but not a significant effect of music type ($p = 0.77$) or interaction between suspense and music type ($p = 0.62$; see Fig. 1C). Recall performance was more accurate for high suspense than low suspense moments but did not differ across the soundtrack versions.

4.3. fMRI effect of suspense across musical soundtracks

One of our motivations for the present study was to test the peripheral vision suppression hypothesis of suspense, using naturalistic viewing presentation and instructions. Increased suspense produced a pattern of decreased activation in the anterior calcarine sulcus − consistent with the results reported previously (Bezdek et al., 2015).

Across the brain, the pattern of activation associated with increases in narrative suspense included widespread increases and decreases that, in general, also replicate our previous findings (Bezdek et al., 2015) (see Fig. 2). Across the three soundtrack conditions, we found increased activity in bilateral occipitotemporal cortex, recruited for higher-order visual processing (Ebisch et al., 2011; Kolster, Peeters, & Orban, 2010; Petit and Haxby, 1999). There was also increased activity in parietal and prefrontal nodes of the ventral attention network. This activity was bilateral, though more pronounced in the right hemisphere. We observed decreased activity in many nodes of the default-mode network, including medial posterior cingulate cortex, ventromedial prefrontal cortex, and bilateral inferior temporal cortex. Significant clusters of activation related to suspense across music conditions are listed in Table 2 (Congruent Music), Table 3 (Incongruent Music), and Table 4 (No Music).

Several brain areas showed consistent suspense-related patterns of activation across all three soundtrack types. These regions are shown in Fig. 2D and listed in Table 5. They include increases in bilateral occipitotemporal cortex and left supramarginal gyrus, as well as decreases in nodes of the default mode network, including the posterior cingulate cortex and the inferior parietal lobule. There were no significant

To more formally test whether the current data replicate our previous results, we used regions-of-interest (ROI) from Bezdek et al. (2015) that showed an effect of suspense and measured whether there were significant effects of suspense in the present data. We used ROIs derived from a functional localizer in the previous study to mask regions of the calcarine sulcus that process the center and peripheral visual field. In that study, we reported that suspense evoked a decrease in peripheral processing (mean signal change = −0.07) and an increase in central processing (mean signal change = 0.07). In the present study, we computed the parameter estimate for each soundtrack type, as well as the average parameter estimate across music types, as shown in Fig. 3. Suspense produced an average increase in central processing (mean parameter estimate = 0.05, $SD = 0.10$, $t(19) = 2.40$, $p < 0.05$), but the average decrease in peripheral processing was not

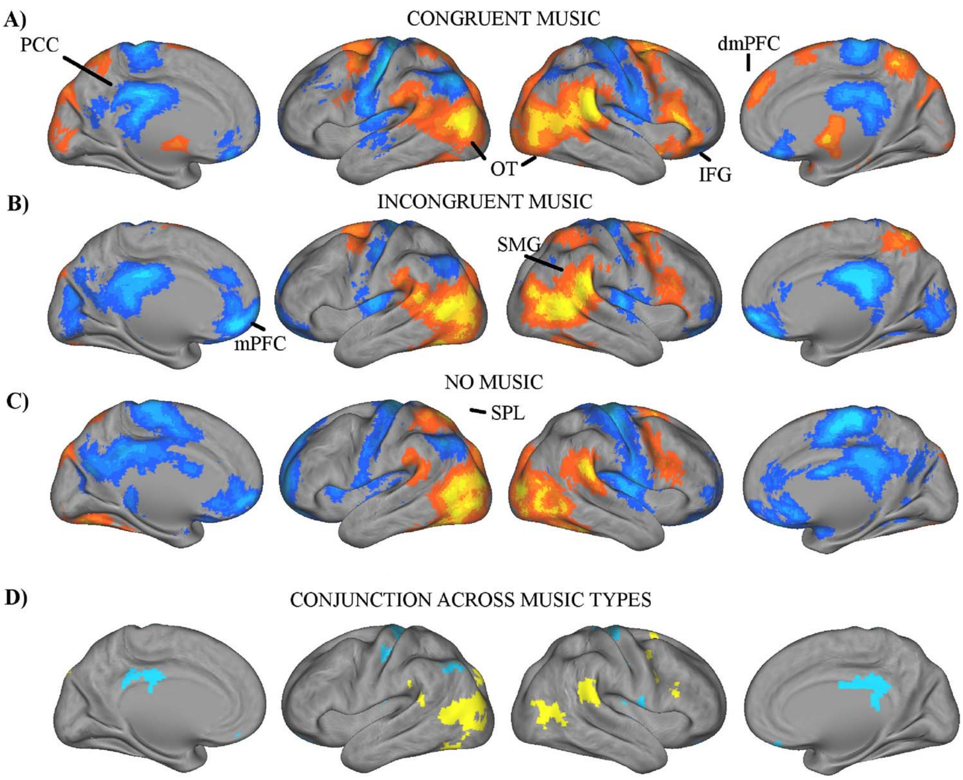

Fig. 2. Increases (shown in warm colors) and decreases (shown in cool colors) in BOLD response to suspense across different soundtrack conditions (FDR corrected $p < 0.05$), projected onto an inflated brain surface. A) Congruent B) Incongruent and C) No music conditions produce visually similar patterns of BOLD activity in response to suspense with no significant differences between music types. D) A conjunction analysis reveals voxels with significant positive or negative suspense-evoked BOLD signal across all three soundtrack conditions. Abbreviations: dmPFC = dorsomedial prefrontal cortex; PCC = posterior cingulate cortex; SPL = superior parietal lobule; OT = occipitotemporal cortex; mPFC = medial prefrontal cortex; SMG = supramarginal gyrus; IFG = inferior frontal gyrus.

significant (mean parameter estimate = −0.03, $SD = 0.08$, $t(19) = 1.70$, $p = 0.11$). However, a repeated measures ANOVA revealed a main effect of music type on peripheral activation, $F(2.38) = 4.73$, $p < 0.05$. Activation in the visual periphery was significantly negative in the incongruent music condition (mean parameter estimate = −0.08, $SD = 0.12$, $t(19) = 2.81$, $p < 0.05$), non-significant in the no music condition (mean parameter estimate = −0.06, $SD = 0.18$, $t(19) = 1.50$, $p = 0.15$), and non-significant positive trend in the congruent music condition (mean parameter estimate = 0.04, $SD = 0.10$, $t(19) = 1.99$, $p = 0.06$). Spherical ROIs with a radius of 10 mm were centered on voxels that showed peak activation in Bezdek et al. (2015), in the default-mode network (precuneus [−3,−72,48], angular gyrus [45,−63,39], posterior cingulate cortex [12,−42,6], superior frontal gy9rus [−21,57,27], inferior parietal lobule [−45,−66,57], middle temporal gyrus [−45,−45,0]) and ventral attention network (right inferior parietal lobule [69,−33,27], right inferior frontal gyrus [48,27,15]). This analysis revealed that suspense evoked a reliable average decrease in the default-mode network (mean parameter estimate = −0.06, $SD = 0.10$, $t(19) = 2.75$, $p < 0.05$) and a reliable average increase in the ventral attention network (mean parameter estimate = 0.08, $SD = 0.08$, $t(19) = 4.64$, $p < 0.001$).

The ANOVA comparing BOLD activation during general film viewing across the three soundtrack types yielded common patterns of activation for all soundtrack types (see Fig. S1, and Tables S1–S4). Film viewing in all three soundtrack conditions elicited increased activation in primary audio and visual cortices and decreased activation in the inferior parietal lobule, a node of the internally-focused default mode network. Paired *t*-tests comparing differences in activity across the three soundtrack types yielded no significant differences between any pair of soundtrack types.

Table 2
Pattern of Activation Related to Increases in Suspense With Congruent Music.

Laterality	Region	BA	*t*-value at peak	Size (voxels)	MNI coordinates of peak voxel		
					x	y	z
Increases							
	Occipitotemporal Cortex	19/39	11.58	4239	−48	−72	9
Right	Inferior Frontal Gyrus	47	8.69	627	57	24	6
	Midbrain		7.94	530	6	−30	−9
Right	Middle Frontal Gyrus	6	7.87	523	24	−3	57
Left	Middle Frontal Gyrus	6	6.96	372	−30	−6	48
Right	Cerebellum		5.06	111	36	−54	−30
Left	Lingual Gyrus	17	3.99	104	−9	−90	0
Left	Cerebellum		4.26	85	−27	−78	−30
Right	Medial Frontal Gyrus	10	4.05	77	6	42	42
Left	Inferior Frontal Gyrus	9	4.17	52	−54	12	27
Decreases							
	Sensorimotor/Cingulate/Medial Frontal Gyrus		−7.69	4478	15	−33	72
Right	Inferior Parietal Lobule	7	−4.64	130	54	−66	45
Left	Superior Temporal Gyrus	21	−5.32	117	−69	−9	0
Right	Cerebellum		−4.03	58	48	−78	−39
Right	Superior Frontal Gyrus	10	−2.87	52	30	72	−6

Table 3
Pattern of Activation Related to Increases in Suspense With Incongruent Music.

Laterality	Region	BA	*t*-value at peak	Size (voxels)	MNI coordinates of peak voxel		
					x	y	z
Increases							
Left	Occipitotemporal Cortex	19/39	6.56	1319	−36	−78	18
Right	Occipitotemporal Cortex	19/39	6.15	818	48	−39	18
Right	Superior Frontal Gyrus	6	4.56	191	12	0	69
Right	Precuneus	7	4.04	163	9	−60	66
Left	Medial Frontal Gyrus	6	4.3	139	−21	0	63
Right	Inferior Frontal Gyrus	45	3.91	90	60	24	21
Right	Fusiform Gyrus	36	4.59	87	42	−36	−27
Decreases							
	Middle Frontal Gyrus	11	−8.48	1851	−36	42	−15
	Lingual Gyrus/Posterior Cingulate Cortex	18/23	−6.8	1297	−3	−36	12
Left	Inferior Parietal Lobule	39	−3.78	278	−51	−75	42
Right	Insula	13	−7.16	273	39	−15	15
Left	Sensorimotor Cortex	3/4	−6.25	251	−18	−27	69
Left	Insula	13	−8.11	233	−39	−18	18
Right	Sensorimotor Cortex	3/4	−5.02	183	18	−33	66
Right	Cerebellum		−4.7	137	51	−69	−42
Right	Middle Frontal Gyrus	10	−3.82	98	45	60	15
Left	Cingulate Gyrus	32	−4.91	54	−12	27	30
Right	Inferior Parietal Lobule	39	−4.66	53	54	−63	51

4.4. Brain activation effect of subsequent memory

We conducted another GLM for each participant comparing activation during film segments that were correctly recalled on the subsequent memory test minus activation during segments that were not correctly recalled (Kim, 2011; Kirchhoff, Wagner, Maril, & Stern, 2000). Correct encoding was associated with increased activity in occipital, parietal and parahippocampal regions, and decreased activity in lateral temporal cortices (see Fig. 4). Table 6 lists significant clusters of activation for the contrast of recalled minus forgotten segments.

5. Discussion

We tested several hypotheses about the effect of narrative suspense on brain activity and on subsequent memory for narrative events. We predicted that moments of increasing narrative suspense would modulate attention-related brain networks. Specifically, we tested for decreased neural processing of the visual periphery and in nodes of the default-mode network, as well as increases in activity in central visual regions and in frontoparietal attention networks. We also tested subsequent memory for narrative events to resolve the question of downstream consequences of narrative suspense, given previous inconsistent results regarding memory for surface details at suspenseful moments (Bezdek and Gerrig, 2017; Bezdek et al., 2015). Finally, we manipulated the accompanying musical soundtrack to test if congruent or incongruent film music modulated brain activity to suspense.

We found suspense produces a pattern of activation suggesting a narrowing of attentional focus. Across all three music conditions, activity in the region that processes the visual center increased as a function of suspense. In the incongruent music condition, activity in the anterior calcarine sulcus, which processes the visual periphery, decreased in activity at suspenseful time points. General film viewing produces an increase in both central and peripheral visual processing regions (see Fig. S1). Our results reveal how this activity is modulated by periods of high versus low suspense. The default-mode network, associated with an inward focus of attention (Buckner et al., 2008), was also less active when suspense increased. Activity increased in the ventral attention network, which is recruited for stimulus-driven attentional shifts (Corbetta and Shulman, 2002).

This pattern of results replicates and extends our previous work studying brain responses to suspense (Bezdek et al., 2015). Our previous study presented films in small central windows with continuous flashing checkerboards in the periphery, and participants were instructed to maintain fixation on a semitransparent fixation cross in the center. The current study used full-screen naturalistic viewing, suggesting that the attentional narrowing effects found in our previous

Table 4
Pattern of Activation Related to Increases in Suspense With No Music.

Laterality	Region	BA	*t*-value at peak	Size (voxels)	MNI coordinates of peak voxel		
					x	y	z
Increases							
Left	Occipitotemporal Cortex	19/39	7.33	1349	−36	−72	−12
Right	Occipitotemporal Cortex	19/39	6.63	664	45	−42	−18
Left	Superior Parietal Lobule	7	5.16	216	−21	−66	57
Right	Superior Temporal Gyrus	13	4.56	176	54	−39	27
	Pons		5.34	87	0	−30	−6
Right	Inferior Frontal Gyrus	9	3.46	85	42	3	33
Right	Middle Frontal Gyrus	6	4.06	69	33	6	69
Left	Superior Temporal Gyrus	13	5.49	66	−57	−39	21
Decreases							
	Sensorimotor/Posterior Cingulate/Medial Frontal Gyrus	3/4/11/23	−7.53	7601	18	−45	24
Right	Cerebellum		−6.01	315	36	−90	−30
Left	Precentral Gyrus	4	−3.45	60	−54	−12	33
Left	Cerebellum		−3.77	56	−45	−75	−39

Table 5
Pattern of Activation For Significant Voxels Related to Suspense Across All Three Soundtrack Types.

Laterality	Region	BA	Size (voxels)	MNI coordinates of center of mass		
				x	y	z
Increases						
Left	Occipitotemporal Cortex	19/39	580	−44	−77.3	9.2
Right	Superior Temporal Gyrus	13	140	59.5	−40	21.8
Right	Occipitotemporal Cortex	19/39	127	48	−66.9	5.8
Decreases						
	Posterior Cingulate Cortex	23	259	7.8	−34.5	23.2
Left	Inferior Parietal Lobule	40	191	−46.7	−66.8	43.4
Left	Middle Frontal Gyrus	10/11	176	−21.8	51.9	−6.7
Left	Precentral Gyrus	4	176	−22.2	−26.7	66.7
Right	Precentral Gyrus	4	169	24.4	−27.4	65.5
Right	Middle Frontal Gyrus	11	81	18.2	34.9	−12.4
Left	Parahippocampal Gyrus	30	56	−21.9	−43.6	7.8

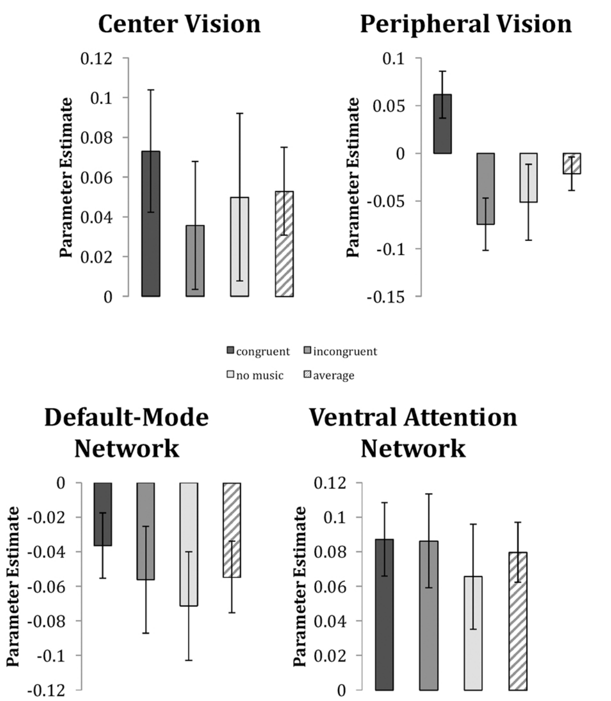

Fig. 3. Effect of suspense in regions of interest. Parameter estimates were drawn from the separate soundtrack types, as well as averaged across the three soundtrack conditions.

work reflect a common response to narrative suspense, rather than an artifact of the experimental task. The extent of significant clusters across the brain was larger in this study than in our previous study, which may be due to the naturalistic viewing or to the larger sample size.

We found that suspense enhanced memory encoding of narrative events. Participants correctly recalled more information from high suspense moments than low suspense moments on the post-viewing memory test. In previous work, we found only limited support for a memory benefit at suspenseful time points when probing for visual features such as the orientation of images (Bezdek and Gerrig, 2017) or the colors of onscreen objects (Bezdek et al., 2015). When comparing the brain activation response to correctly versus incorrectly recalled film segments, we found increased activity in the parahippocampal gyrus, as well as occipital and parietal regions. These results accord with other subsequent memory studies (Kim, 2011), which typically find ventral temporal activation related to successful encoding, including another study that examined memory for film content (Hasson, Furman, Clark, Dudai, & Davachi, 2008). Together these results provide support for a central claim of transportation theory: Narrative experiences will at times increase attentional processing of narrative content, which will in turn lead to deeper memory encoding and more successful subsequent recall. This effect may be selective, enhancing encoding of the actions and goals of characters, but not incidental surface details such as image color or orientation.

We found that congruent suspenseful music modulates the brain response to suspense. Specifically, the suppression of peripheral visual processing in the calcarine sulcus is weaker in excerpts accompanied by congruent music than those accompanied by incongruent happy or calm music. We speculate that this effect may be due to differences in the suspense time courses across music versions. The increases in suspense due to visual events might cause the peripheral suppression effects, whereas the additional increases in reported suspense due to suspenseful music may increase arousal but not suppress peripheral visual processing. The lack of broader differences in brain activation due to the music accompaniment is surprising, given a plurality of studies that have reported effects of manipulating the congruency of the musical soundtrack (Boltz et al., 1991; Boltz, 2004; Bullerjahn and Güldenring, 1994; Marshall and Cohen, 1988; Tan et al., 2007; Vitouch, 2001). It is possible that the suspenseful scenes that we used were highly ‘transporting’ even in the no music condition, which left less room for the soundtrack manipulation to modulate brain activity or memory performance. Other research has reported that the presence of music enhances reported narrative transportation, but only when the mood of the music shares emotional congruence with the mood of the narrative (Costabile and Terman, 2013). It is also noteworthy that in our study, any accents in the music were not synchronized with events in the films, in contrast to how filmmakers often use musical scores. This difference may have increased the extent to which music and narrative events served as separate modulators of suspense, rather than the music directly modulating suspense felt in response to narrative events. Future research should examine congruency with narratives that evoke different emotional responses, to test if the results we report are specific to suspense.

Though we found differences in brain activity based on the musical soundtrack, we did not find differences in memory performance. Participants recalled high-suspense time points more accurately than low-suspense time points, but performed similarly across all musical soundtrack types. These results are surprising given related research that has found encoding detriments in cases of incongruent music accompaniment (Boltz et al., 1991). We speculate that our lack of significant music differences on memory performance might be due to the dominance of the visual narrative, the low number of film excerpts, or the small sample size for a memory experiment.

Overall, the results of our study provide converging evidence for how suspense affects attention and memory. Suspenseful moments produce increased processing of the visual center, with a pattern suggestive of increased stimulus-driven attention and decreased internally

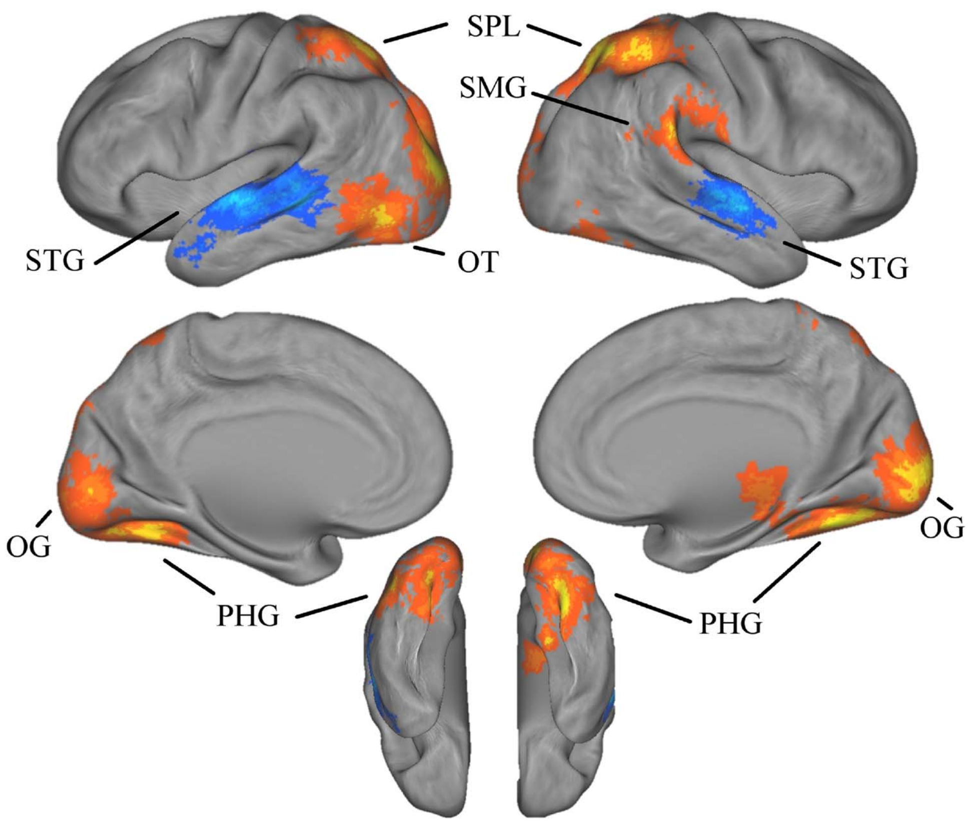

Fig. 4. Subsequent memory effect. Depicted are lateral (top), medial (middle), and ventral (bottom) views of the contrast of segments that were later correctly recalled minus segments that were incorrectly recalled, FDR corrected $p < 0.05$. STG = superior temporal gyrus; OG = occipital gyrus; PHG = parahippocampal gyrus; SPL = superior parietal lobule; SMG = supramarginal gyrus; OT = occipitotemporal cortex.

Table 6
Pattern of Activation for Correctly Recalled Film Segments Minus Forgotten Segments.

					MNI coordinates of peak voxel		
Laterality	Region	BA	*t*-value at peak voxel	Size (voxels)	x	y	z
Increases							
Left	Middle Occipital Gyrus	18/19	7.29	421	−24	−90	9
Bilateral	Lingual Gyrus	17/18	5.99	404	0	−87	−9
Right	Superior Parietal Lobule	7	8.18	295	24	−66	54
Left	Fusiform Gyrus	19/37	5.52	265	−45	−66	−9
Left	Superior Parietal Lobule	7	6.54	210	−30	−66	63
Right	Fusiform/Parahippocampal Gyrus	19/27	5.28	202	33	−66	−9
Right	Inferior Parietal Lobule	40	4.48	75	66	−36	24
Decreases							
Left	Middle Temporal Gyrus	21/22	−5.76	219	−57	−36	−3
Right	Middle Temporal Gyrus	21	−4.41	104	60	−15	−6
Left	Superior Temporal Gyrus	38	−5.44	64	−54	15	−27

focused attention. These attentional effects are complemented by enhanced encoding of narrative events, resulting in improved performance on a subsequent memory test. These processes may coordinate through the interaction of activated task files, which are integrated knowledge structures including one's task goals, motivation, and relevant stimulus and response dimensions required for goal directed behavior (Schumacher and Hazeltine, 2016). The activated task file for "viewing films" may coordinate attentional focus and memory encoding as narrative suspense fluctuates. Our findings help to elucidate how components of narrative transportation are processed in the brain as well as understand how moment-by-moment changes in emotional suspense affect cognition during naturalistic viewing.

Funding

This work was supported by the Defense Advanced Research Projects Agency contract #D12PC00397

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.biopsycho.2017.07.020.

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