NEURAL CORRELATES OF NARRATIVE STRUCTURE DURING NATURALISTIC AUDIOVISUAL FILM USING FUNCTIONAL MAGNETIC RESONANCE IMAGING

CHRISTINA HAINES
Bachelor of Science, University of Lethbridge, 2020

A thesis submitted
in partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE

in

NEUROSCIENCE

Department of Neuroscience
University of Lethbridge

LETHBRIDGE, ALBERTA, CANADA

NEURAL CORRELATES OF NARRATIVE STRUCTURE DURING NATURALISTIC AUDIOVISUAL FILM USING FUNCTIONAL MAGNETIC RESONANCE IMAGING

CHRISTINA HAINES

Date of Defence: October 5th, 2023

Dr. Chelsea Ekstrand	Assistant Professor	Ph.D.
Dr. Robbin Gibb	Professor	Ph.D.
Thesis Co-Supervisors		
Dr. Robert McDonald	Professor	Ph.D.
Thesis Examination Committee Member		
Dr. David Euston	Associate Professor	Ph.D.
Thesis Examination Committee Member		
Dr. Artur Luczak	Professor	Ph.D.
Chair, Thesis Examination Committee Member		

DEDICATION

For my family.

Thank you for your unwavering support and encouragement. I love you all.

And for Ivy and Mabel, of course 🐾.

ABSTRACT

A narrative is defined as a description of interconnected events, whereby forming narratives requires sustained attention and simultaneous integration of information to navigate and track events and assign them along an immersive timeline (Martinez-Conde et al., 2019). Narratives, in the form of film, plays, and television, offer a unique opportunity to assess brain functions in situations more akin to the “real-world”. However, most neuroimaging studies examining narrative formation have used static stimuli (e.g., still images, disconnected sentences, or incoherent narratives) that do not encapsulate the complexity of narrative formation in the everyday life. It is currently unknown how the brain processes “real-world” information into coherent narrative events. The current research uses data from the Naturalistic Neuroimaging Database (Aliko et al., 2020) to examine the neural correlates of narrative processing using functional magnetic resonance imaging (fMRI). In four experiments, we assessed neural synchrony patterns implicated in long-term narrative processing and identified networks associated with distinct phases of narrative processing and conveyed the dynamic changes of cognitive demands as a narrative evolves. Results from this study emphasize the evolving cognitive demands intrinsic to narrative structure, reflecting dynamic changes in neural synchrony. These findings extend beyond research advancement, by bridging the gap between cognitive neuroscience and “real-world” narrative processing.

ACKNOWLEDGEMENTS

I would like to start by giving my sincerest acknowledgements to my supervisory committee, who have granted me this phenomenal opportunity and have guided me through this journey.

To my supervisor, Dr. Chelsea Ekstrand. I would like to say thank you for giving me a chance to pursue my Master's Degree, without you I would not have pursued my degree at the University of Lethbridge and be given the opportunities I was. Your guidance has provided me with knowledge but also the ability to tackle challenges with enthusiasm, embrace learning with passion, and grow my dedication to achieving whatever I set my mind to.

I would also like to thank my committee members for their feedback and help, which consisted of my co-supervisor Dr. Robbin Gibb, and committee members Dr. Robert McDonald, and Dr. David Euston.

Lastly, I extend my heartfelt gratitude to my colleagues from the Ekstrand Neuroimaging Lab: Josh Craig, KiAnna Sullivan, and Keva Klamer. As a team, we were able to overcome challenges that I am sure we never anticipated encountering during our academic journeys. I am grateful for the opportunity to have tackled these challenges and grown with you three through them. I am lucky to have spent the last 2 years with you all.

TABLE OF CONTENTS

LIST OF TABLES

Table No. **Page**

Chapter 2: Examining the Neural Correlates of Narrative Processing

LIST OF FIGURES

Chapter 1: General Introduction

Chapter 2: Examining the Neural Correlates of Narrative Processing

Chapter 3: General Discussion

LIST OF ABBREVIATIONS

ACC	Anterior Cingulate Cortex
AG	Angular Gyrus
BOLD	Blood Oxygen Level Dependent
EPI	Echo Planar Imaging
FEF	Frontal Eye Field
FDR	False Discovery Rate
fMRI	Functional Magnetic Resonance Imaging
GLM	General Linear Model
IFG	Inferior Frontal Gyrus
IPS	Intraparietal Sulcus
ISC	Intersubject Correlation
LME	Linear Mixed Effects
MFG	Middle Frontal Gyrus
mPFC	Medial Prefrontal Cortex
MTG	Middle Temporal Gyrus
NNdB	Naturalistic Neuroimaging Database
PCC	Posterior Cingulate Cortex
PFC	Prefrontal Cortex
PHC	Parahippocampal Cortex
RSC	Retrosplenial Cortex
SPL	Superior Parietal Lobule
TE	Echo Time
TPJ	Temporoparietal Junction
TR	Repetition Time

CHAPTER 1: General Introduction

1.1 Narrative Processing

A narrative is a coherent representation of actual or fictional events designed to connect experiences (Martinez-Conde et al., 2019). Narrative comprehension is complex, requiring sustained attention and integration of cognitive inputs. Narratives can come in various forms, including written word, spoken stories, film, video games, and virtual reality (Willems et al., 2020). The encoding of narratives relies on an innate human ability to process semantic information, recall memories, engage with emotional content, and interact socially. Through this intricate cognitive process, individuals can perceive, categorize, construct, and store a cohesive representation of information. As new events and experiences are encountered, the human brain possesses the remarkable capacity to adapt and transform mental representations of people, events, and environments to align with the dynamically changing world. Not only can these representations be modified, but they can also be assigned to a mental timeline, creating a sense of temporal coherence. Further, the presence of new information can prompt individuals to revise and update existing narrative representations, allowing for a flexible and adaptive understanding of personal stories. Thus, narratives serve as a means for connecting experiences and constructing meaningful representations of the world.

The ability to form and maintain coherent narratives is a fundamental aspect of human cognition, playing a crucial role in understanding the world and our own experiences. Impairments in this process can significantly impact everyday functioning and overall well-being. A condition that exemplifies such impairments is dementia, which is characterized by a progressive decline in cognitive abilities, including memory, thinking, and reasoning (Gale et al., 2018). The formation and maintenance of autobiographical narratives is profoundly affected in individuals with dementia. Research conducted by Bréchet et al. (2021) indicates that severe deficits in memory contribute to this impairment. Memories, which serve as building blocks for narratives, become fragmented, distorted, or lost, making it challenging for individuals with dementia to construct coherent and cohesive personal stories. The disjointed nature of personal narratives can lead to confusion, frustration, and a sense of identity loss. This impairment further contributes to the deterioration of autobiographical narratives, making it harder for individuals to make sense of their past and present experiences. Previous research shows that the hippocampus, prefrontal cortex, temporal lobes, and parietal lobes show atrophy in dementia (Gale et al., 2018). These areas of the brain have vast behavioral and cognitive roles in human behavior, and are involved in processes like memory, attention, and semantic processing.

1.2 Cognitive Processes Required for Narrative Processing

Narrative formation is complex and engages various short-term and long-term cognitive processes to comprehend and create meaningful representations. To fully understand the cognitive demands of narrative processing, it is important to understand the roles of visuospatial attention, semantic memory, and episodic memory and the neural correlates that support these processes. First, visuospatial attention plays a fundamental role in narrative processing by enabling individuals to focus on relevant information and filter out distractions. It involves directing cognitive resources toward specific aspects of the narrative, such as characters, events, or plot developments. Research has shown that attentional engagement with stimuli results in correlations within visual and auditory areas (Jääskeläinen et al., 2020). Second, semantic memory refers to the knowledge about the world, including concepts, facts, and general knowledge, that individuals have accumulated over their lifetime (Binder et al., 2009). In narrative processing, semantic memory allows for encoding and storage of information related to the environment, characters, objects, and self. Third, episodic memory is responsible for encoding and retrieving personal experiences or episodes (Ritchey & Cooper, 2020). In the context of narrative processing, episodic memory plays a crucial role in recollecting and reconstructing memory representations built throughout exposure to the narrative. This allows for the integration of new information into the evolving mental representation of the narrative. Overall, visuospatial attention, semantic memory, and episodic memory are interconnected cognitive processes that contribute to the comprehension and encoding of narratives. Attention facilitates the selection and allocation of cognitive resources, while semantic memory provides a repository of knowledge to make sense of narrative content. Episodic memory supports the retention and integration of new information into the evolving narrative representation. These processes rely on neural networks distributed across various brain regions.

1.2.1 Neural Correlates of Visuospatial Attention

Visuospatial attention plays a crucial role in narrative processing by helping filter out irrelevant information and focus on relevant and significant aspects of a stimulus. According to the Corbetta and Shulman (2002) model of attention, there are two cortico-cortical neural networks involved in orienting attention that are primarily right-lateralized. The dorsal attention network is a frontoparietal network responsible for goal-directed selection of stimuli and responses and consists of the frontal eye field (FEF) and the intraparietal sulcus (IPS)/superior parietal lobule (SPL). Goal-directed attention is described as the voluntary allocation of attention to things within our surroundings that contribute to a defined goal (Van Ede et al., 2020). The ventral attention network is a ventral frontoparietal network involved in bottom-up attentional selection, also known as stimulus-driven attention. In this case, attentional focus is involuntarily captured by the characteristics of the external environment or stimuli, such as its sensory features

(Van Ede et al., 2020). This system consists of the temporoparietal junction (TPJ) and the ventral frontal cortex (including the inferior frontal gyrus (IFG) and middle frontal gyrus (MFG)). Together, the dorsal and ventral attention networks are responsible for allocating and directing attention to visual and spatial information in the environment. This enables us to selectively process and prioritize visual stimuli based on its spatial location and relevance. In the context of narrative processing, the dorsal attention network is involved in generating a coherent representation of the narrative (Assouline & Mendelsohn, 2019). This system allows us to selectively attend to narrative elements that contribute to the construction of the story. These systems work together to guide attention during interactions and within the visual environment, ensuring that attention is directed to the most salient and significant elements of the narrative (Corbetta & Shulman, 2002). This coordination helps to construct a coherent representation of the narrative by prioritizing relevant information and filtering out distractions, the network of these regions is seen in Figure 1.1.

These aforementioned regions have been further implicated in various studies assessing visuospatial attention. For instance, research has confirmed the critical role of the SPL in regulating visuospatial attention (Wu et al., 2016). The FEF and IPS are significant contributors to the dorsal attention network, which controls the voluntary allocation of attention (Meehan et al., 2017). Additionally, the TPJ has been associated with reorienting attention to task-specific stimuli (Dugué et al., 2018). These studies collectively validate the Corbetta and Shulman model's efficacy and further support the involvement of these regions in visuospatial attention.

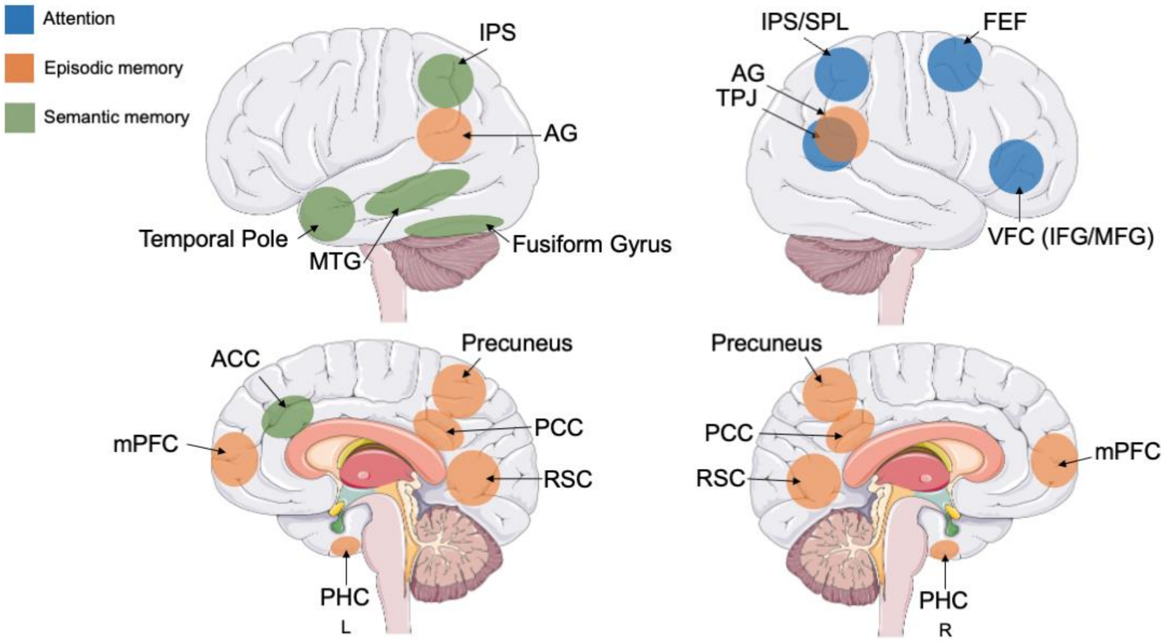


Figure 1.1. Narrative Processing Model. This figure depicts the regions we hypothesize to be involved in narrative processing. Three prominent cognitive systems—semantic memory, episodic memory, and attention—are shown and their respective neural correlates.

1.2.2 Neural Correlates of Semantic Memory

A critical element of narrative understanding is the ability to perceive, encode, and retrieve context-relevant information during and after interpersonal interactions. This process, known as semantic processing, is essential for accessing and utilizing stored knowledge about the world, including people, objects, relations, self, and culture. In the context of narrative, semantic processing and memory lay the foundation for constructing a cohesive neural representation (León, 2016). Several brain regions have been identified as important components of the semantic system, including the temporal pole and anterior cingulate cortex (ACC), both of which have been identified as semantic hubs, as well as the fusiform gyrus, intraparietal sulcus (IPS), posterior middle temporal gyrus (MTG), and prefrontal cortex (PFC) which are supporting structures within the semantic network. Hubs are regions in the brain that integrate information from different sensory modalities and form semantic concepts by connecting information from different modalities (Zhao et al., 2017). Research suggests that the semantic system is predominantly left-lateralized. This network comprises regions distributed throughout the brain. Prior research has established connections between these regions and semantic memory. For example, the posterior MTG has been implicated in the integration of automatic semantic retrieval (Davey et al., 2016). Moreover, a study examining the neuropsychological assessment of semantic dementia (Ding et al., 2020) directly linked the degree of semantic impairment to bilateral temporal pole atrophy.

1.2.3 The Neural Correlates of Episodic Memory

Episodic memory refers to the ability to encode and retrieve representations of daily experiences, allowing individuals to form coherent mental representations of personal interactions and personally relevant information over extended time scales (Dickerson & Eichenbaum, 2010). It enables individuals to create and recall detailed mental representations of events involving themselves, contributing to a sense of self and continuity of personal experiences (Dickerson & Eichenbaum, 2010). A theory of episodic memory, the posterior medial episodic network, provides a neural basis for the construction of dynamic and detailed mental representations. The posterior medial episodic network consists of several brain regions: the hippocampus, parahippocampal cortex (PHC), retrosplenial cortex (RSC), precuneus, angular gyrus (AG), posterior cingulate cortex (PCC), and medial prefrontal cortex (mPFC). Drawing upon prior research, the precuneus, PCC (Tylén et al., 2015), and AG (Kauttonen et al., 2018) have all been associated with narrative processing. Consequently, these regions may also play a role in episodic memory related to narrative processing. The PHC is strongly implicated in episodic memory, particularly contextual associations (Bar et al., 2008), which are fundamental elements of various functions, including episodic memory (Aminoff et al., 2013). Furthermore, the precuneus has been associated with memory deficits in early Alzheimer's disease, and the application of transcranial magnetic stimulation focused on the precuneus has shown selective improvement in episodic memory (Koch et al., 2018). Additionally, much like the PHC, the precuneus is involved in generating rich contextual associations and activates during correct source retrieval (Lundstrom et al., 2005). These findings further support the postulates of the posterior medial episodic network and underscore the strength of its assumptions.

1.3 Naturalistic Cognitive Processing

Exploring how narratives are integrated in the brain within experimental settings presents a set of formidable challenges. One major obstacle stems from the fact that narrative processing unfolds across extended timescales—ranging from minutes to years—making it difficult to capture effectively in conventional research designs. Additionally, untangling narrative construction from other cognitive processes is challenging due to its multifaceted nature. To deal with these complexities, an emerging consensus proposes integrating naturalistic stimuli into research protocols, which better replicate the perceptual, cognitive, and emotional demands inherent in real-life (Vanderwal et al., 2019). Examples of naturalistic stimuli include audiovisual movie clips, TV advertisements, spoken narratives, interactive encounters with virtual agents, gaming environments, and virtual reality (Sonkusare et al., 2019). By incorporating these more true-to-life stimuli into research designs, researchers gain the unique vantage point of understanding how individuals perceive and interpret real-world situations within a controlled research environment. Notably, movies have been shown to be invaluable tools for examining the brain mechanisms underlying various aspects of human cognition (Jääskeläinen et al., 2021). Embracing naturalistic stimuli can allow us to uncover the cognitive processes underpinning narrative processing within contexts that more closely mirror real-life experiences.

However, with this shift to naturalistic stimuli comes the computational challenge of analyzing and interpreting complex neural responses associated with multiple task demands. To address this, intersubject correlation (ISC) analysis has been proposed (Hasson et al., 2010; Nastase et al., 2019). ISC identifies neural activity that is shared between subjects by examining correlations in hemodynamic responses across the time course of a naturalistic stimulus (Pajula et al., 2012). The primary objective of ISC analysis is to uncover shared neural activity, also known as neural synchrony, among a large proportion of participants. Using this analysis, it is possible to create maps illustrating the distribution of neural synchrony across the brain. ISC analysis is commonly employed with naturalistic stimuli as it can reveal networks of brain regions that consistently synchronize during certain tasks, experiences, or cognitive processes, providing insight into how humans process and react to the same or similar situations (Hasson, Malach et al., 2010).

1.4 Neural Correlates of Narrative Processing Using Naturalistic Stimuli

Narrative processing is complex and requires multiple cognitive skills, including (but not limited to) semantic processing, attention, and memory. Previous research on the neural mechanisms of narrative understanding has consistently identified several brain areas, including the precuneus, PCC, TPJ, and temporal pole (Cavanna & Trimble, 2006; Utevsky et al., 2014). The precuneus, a key node in the default mode network, is believed to be instrumental in various higher-order cognitive functions such as visuospatial processing, episodic memory retrieval, self-processing, and consciousness (Cavanna & Trimble, 2006). Brain areas in the semantic system also play a role in narrative processing. For example, Fatma Deniz et al. (2019) investigated how semantic information in narratives is represented in the brain independent of the modality used to process the narrative. They used fMRI to assess blood oxygen level dependent (BOLD) activity while participants either listened to or read, the same narrative (i.e., 10–15-minute stories taken from The Moth Radio Hour). In the reading condition, the timing of each word appearing on the screen was matched to the timing of the auditory delivery. Using voxel-wise modelling to estimate semantic selectivity both in each voxel independently and in both listening and reading modalities, they showed distributed semantic regions across the lateral temporal cortex, ventral temporal cortex, lateral parietal cortex, medial parietal cortex, mPFC, superior PFC, and inferior PFC. Thus, semantic representations formed by either listening to or reading narratives were independent of the modality in which they were presented.

In line with this, previous research from Tylén et al. (2015) used fMRI and incoherent and coherent podcast episodes to study the neural correlates of plot formation. Participants listened to five coherent narrative sessions with randomly chosen episodes from different narratives during fMRI. A two-level general linear model (GLM) analysis contrasting coherent events to incoherent events showed significant activation in the PCC, precuneus, anterior prefrontal cortex, orbitofrontal cortex, right hippocampus, and right caudate nucleus, as well as large areas of the temporal lobes extending from the temporal pole to the TPJ. These areas are involved in continuous tracking and integration of information during a coherent narrative, which could be implicated in narrative processing tasks.

Kauttonen et al. (2018) looked at the formation of key plot points of a narrative in the brain over longer timescales using naturalistic stimuli. Specifically, the researchers sought to investigate the mechanisms underlying cued recall and how memories were formed over the course of continuously evolving events in an audiovisual movie. To do so, 25 participants watched one of two versions of the film *Memento* (Nolan, 2001) during fMRI, one presented in reverse chronological order (the original version of the film) with brief scenes that overlap and serve as memory cues for the viewer, and an altered version of the film edited to follow chronological order. Multivariate event-related pattern analysis and representational similarity analysis revealed significant clusters of brain activity in several regions when comparing between participants who watched the film in reverse chronological order versus those who watched it in chronological order. These regions included the frontal pole, cingulate and paracingulate gyrus, precuneus, AG, and the MFG. These results suggest that these specific brain regions play a crucial role in processing the narrative of the film throughout its duration.

Overall, these studies provide valuable insight into the neural correlates of narrative processing. Thus, based on previous research, the areas proposed to be involved in narrative processing in naturalistic stimuli include attentional areas such as the right FEF, SPL, IFG/MFG, and TPJ, semantic processing areas including the left temporal pole (hub), ACC (hub), fusiform gyrus, IPS, MTG, and PFC, and episodic memory areas such as the mPFC, precuneus, PHC, hippocampus, RSC, AG, PCC (see Figure 1.1). However, one aspect that remains largely unexplored is the dynamic nature of how cognitive demands evolve over the course of a narrative. While existing research has focused on specific cognitive processes such as cued recall, the role of context in narrative, and plot formation on a short time scale, there is a need to investigate how these processes interact and transform as the narrative unfolds. By examining evolving cognitive demands within a narrative, we can gain a more comprehensive understanding of the complex interplay between cognitive processes and the narrative structure, and how individuals adapt their cognitive resources to meet the changing requirements of long-term memory integration.

1.5 Classical Film Plot Development

Films provide extensive multimodal and emotionally laced information to viewers, which provides an ideal model to assess the way the brain processes real-world information in a research setting. They also allow for the assessment of narrative processing on a more defined scale, rather than in the expansive sense of one's own narrative. Based on previous research and drawing on classic film theory, it has been established that the structure of a "classic Hollywood film" consists of three acts: Set-up, Development, and Resolution (Cutting et al., 2011). This three-act structure traces its origins back to the days of Aristotle (Cutting, 2016) and continues to be widely employed in present-day Hollywood movies (Brütsch, 2015). On average, Set-up is the first third of the narrative, Development occupies the middle third, and Resolution forms the final third (see Figure 1.2).

Act I, known as the Set-up act, serves to introduce the protagonist and establish their world. The Set-up may also introduce a central antagonist, allowing the audience to identify the hero, the villain, and the overarching goals. Act II, the Development act, primarily revolves around the protagonist facing obstacles. Each obstacle becomes progressively more challenging as the story unfolds. At the midpoint of this act, the main character typically reaches a pivotal moment where they must decide whether to continue pursuing the goal or give up. By the end of Act II, the protagonist is confronted with the most significant obstacle. Act III, the Resolution act, represents the final section of the film and centers on the protagonist's ability to rally and overcome the ultimate obstacle, leading to the climactic point and a conclusion. This conclusion often mirrors the success or failure in reaching the goal established in Act I. Modern-day Hollywood films adhere to a discernible narrative pattern, which enables the production of movies with complex narrative structures while maintaining limited variation in overall plot formation (Guha et al., 2015).

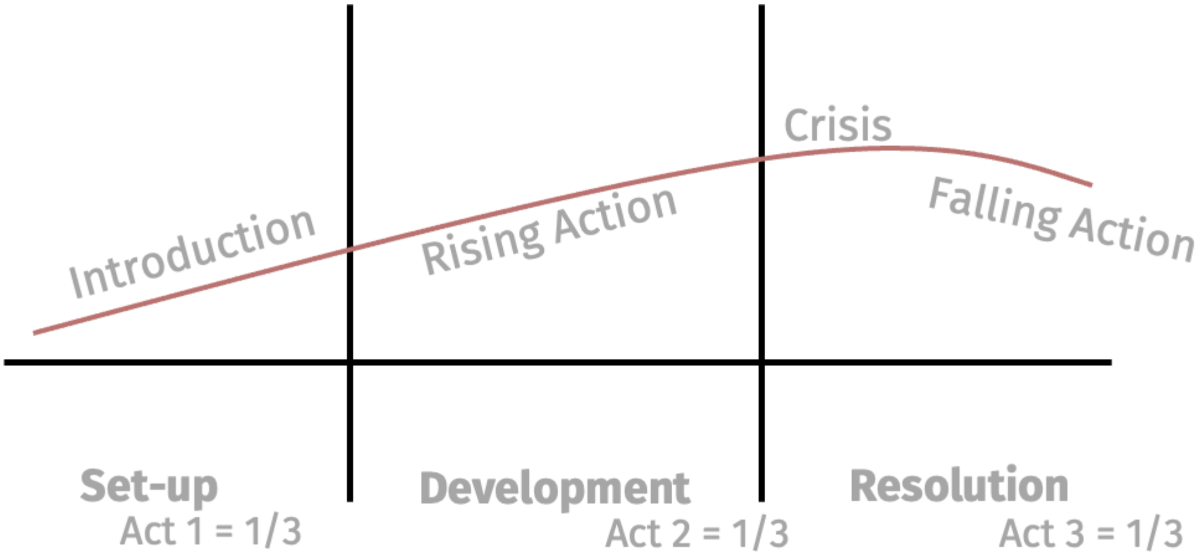


Figure 1.2. Three-Act Narrative Structure. This figure illustrates the classic three-act structure commonly used in narrative. Act I (Set-up) establishes the setting, introduces the characters, and presents the initial conflict. Act II (Development) introduces the main conflict, obstacles, and builds tension. Act III (Resolution) brings the story to its climax, resolves the conflict, and provides a satisfying conclusion.

1.6 Current Research

The experiments presented in this thesis sought to examine the brain regions involved in narrative processing over time using a naturalistic paradigm. To achieve this, we used data from the Naturalistic Neuroimaging Database (NNdB; version 2.0.0; Aliko et al., 2021) of participants who watched one of ten full-length audiovisual movies during fMRI. The films included in the NNdB were divided into sections based on the classical film plot theory previously discussed: Set-up, Development, and Resolution. By examining each section individually and analyzing the differences in neural synchrony between the stages, this research aimed to unravel changes in brain synchrony associated with changing cognitive task demands as the storyline progressed. Our general hypothesis was that, over the course of the narrative, cognitive demands would change, thus leading to changes in neural synchrony in attention, semantic processing, episodic memory, and narrative processing regions across the three acts.

Over the course of four experiments, we sought to examine different aspects of narrative processing. The first experiment focused on assessing the neural correlates of Set-up, Development, and Resolution in a single film by examining neural synchrony between participants, as measured by ISCs. The second experiment explored differences in neural synchrony between the different stages of the film within a single movie. The third experiment examined neural synchrony related to the Set-up, Development, and Resolution acts across 10 different films. By generalizing the findings across a broad range of narratives, it aimed to identify commonalities and differences in the neural correlates and cognitive processes occurring within each section of the films and attempted to eliminate any film specific sensory synchrony. The final experiment focused on examining differences in neural synchrony between the stages of the film across 10 different films. The use of 10 different films allows for the examination of narrative processing without any individual film driving the resulting synchrony, as both within and between movie pairs are included in the analysis. By investigating changing patterns of neural synchronization, this thesis aimed to elucidate how the communication and coordination between brain regions varied as the narrative progressed. This research will contribute to our understanding of the cognitive mechanisms required to integrate information into coherent narratives over longer timescales by providing comprehensive insights into changes in synchrony related to specific cognitive demands. More broadly, the findings from this thesis could shed light on the effects of degeneration and injury resulting in deficits in the perception and processing of narratives, providing valuable information for clinical populations with narrative-related cognitive impairments.

CHAPTER 2: Examining the neural correlates of narrative processing during naturalistic audiovisual film using fMRI

Experiment 1

2.1 Introduction

In Experiment 1, our objective was to investigate neural synchrony in regions linked to episodic memory, semantic memory, attention, and overall narrative processing throughout distinct stages of a complex, audiovisual narrative. To achieve this, we used fMRI data from participants who watched the movie *500 Days of Summer* (Webb, 2009). This film was chosen due to its adherence to the three-act structure commonly employed in contemporary Hollywood movies, as discussed in Section 1.5 of the introduction (Sharma & Rajamanickam, 2015). To carry out the experiment, we divided fMRI data into three equal segments based on the total number of volumes acquired, which correspond to the Set-up, Development, and Resolution acts. It is important to note that our division of the data was designed to capture potential changes in cognitive processes across the progression of the narrative. In general, we hypothesized that synchrony in brain areas associated with attention, semantic memory, episodic memory, and narrative processing would be unique for the Set-up, Development, and Resolution phases. Specific hypotheses for each section are outlined below.

Set-up

This section of the experiment aimed to investigate brain regions associated with the Set-up phase of the film, which involves substantial world and character building, memory formation, and information integration. In terms of the cognitive demands of processing a narrative at this stage, we hypothesized that areas involved in attention, semantic memory, and episodic memory would all show high levels of synchronous activity across participants.

Additionally, the Set-up section is characterized by a substantial influx of narrative information, therefore the encoding of both semantic and episodic memory becomes essential, in turn translating to synchronous activity. Further, the heightened dorsal attentional requirements stem from the goal-directed nature of attention in this segment. Thus, we hypothesized that regions associated with goal-directed attention (right FEF and IPS/SPL), semantic memory (left ACC, temporal pole, IPS, fusiform gyrus, and MTG), and episodic memory (bilateral AG, precuneus, PCC, RSC, PHC, hippocampus, and mPFC) would exhibit significant synchrony as participants construct cohesive narrative representations.

Development

This section of the experiment sought to identify brain regions associated with the Development phase of the film, where the characters are confronted with obstacles and engage in decision-making processes to overcome them. This portion is closely related to problem-solving, as the characters navigate through challenging situations. During this portion of the narrative, we hypothesized that areas involved in goal-directed attention, mainly the right FEF and IPS/SPL, would show less synchrony, but areas involved in episodic memory (bilateral AG, precuneus, PCC, RSC, PHC, hippocampus, and mPFC), semantic memory (left ACC, temporal pole, IPS, fusiform gyrus, and MTG), and stimulus-driven attention (right TPJ and IFG/MFG) would continue to show strong synchrony. This segment is still characterized by a consistent influx of both semantic and episodic information, translating to synchronous activity in these regions.

Resolution

This section aimed to identify brain regions associated with the Resolution phase of the film. This section is linked to the main character's ability to draw inferences and reach a satisfying conclusion, where the most challenging obstacle is overcome, and the loose ends of the story are tied up. We hypothesized that areas involved in goal-directed attention (right FEF and IPS/SPL), semantic memory (left ACC, temporal pole, IPS, fusiform gyrus, and MTG), and episodic memory (bilateral AG, precuneus, PCC, RSC, PHC, hippocampus, and mPFC) will show decreased synchrony during this final section of the narrative, while areas involved in stimulus-driven attention (right TPJ and IFG/MFG) will show synchronous activity. This segment is marked by the resolution of narrative elements and the conclusion of the story's content. The introduction of new information is infrequent, reducing the necessity for goal-directed attention. Consequently, the sensory aspects of the film are expected to dominate attention. With regard to semantic and episodic memory, the absence of new plot-driven information may lead to less synchrony in these regions in the final stages of the narrative.

2.2 Methods

Participants

For this study, we used preprocessed fMRI data from the NNdB (Aliko et al., 2021) v2.0. This database consists of 86 functional datasets of participants that watched one of ten full-length feature films. For this experiment, we utilized functional datasets of twenty participants (10 female, average age = 27.7 years) who watched the film *500 Days of Summer* (Webb, 2009) during fMRI. All participants were right-handed, native English speakers, had unimpaired or corrected-to-normal vision, no hearing impairments, and had no history of neurological or psychiatric illnesses (see Aliko et al., 2021 for detailed information).

Materials and Stimuli

500 Days of Summer (Webb, 2009) was selected from the 10 films utilized in the NNdB for the following reasons: This film follows the classic 3-act structure laid out in section 1.5 of the introduction and has the largest number of acquired datasets per movie in this database.

Data Acquisition

All data acquisition details can be found in Aliko et al. (2021). In summary, MRI data was collected on a 1.5T Siemens Magnetom Avanto scanner with a 32-channel head coil. FMRI data was acquired using an echo planar imaging (EPI) sequence with a 4x multiband factor and the following scanning parameters: repetition time (TR) of 1s, echo time (TE) of 54.8ms, flip angle of 75°, and a resolution of 3.2mm isotropic. A T1-Magnetization Prepared Rapid Acquisition Gradient Echo anatomical scan was acquired with a TR of 2.73s, TE of 3.57ms, and a resolution of 1.0mm^3. To ensure optimal audio quality, noise-attenuating headphones were used. Participant attention was closely monitored using a camera fixated on their eyes. The visual part of the films was presented through a mirror-reversing LCD projector. To maintain the naturalistic viewing experience and minimize interruptions, the films were played with minimal breaks. However, due to the limitations of the EPI sequences and software, the films were played in 40–50-minute segments. These breaks were intentionally timed to occur during scenes that did not contain crucial plot information or dialogue.

Data Preprocessing

Data preprocessing was conducted by Aliko et al. (2021). Briefly, because the films were obtained in separate runs to accommodate EPI and software requirements, the time series were concatenated after undergoing timing correction preprocessing using AFNI's *'3dTproject'*. In addition to the concatenation, all functional scans underwent the following preprocessing steps: time shifting, despiking, volume registration, MNI alignment, mask time-series, smoothing 6mm FWHM, detrending with regressors (e.g., for motion), timing correction, manual ICA denoising (Aliko et al., 2021) using AFNI's afni_proc.py pipeline (Cox, 1996)(Taylor et al., 2018) to enhance the statistical significance of the resulting *t*-stats and produce cleaner functional files.

These steps process the raw data in the following ways: time shifting (slice timing correction), aligns acquisition times for different data slices, and despiking removes high-amplitude signal fluctuations. Volume registration reduces the impact of motion artifacts by aligning all data volumes to a common reference. MNI alignment standardizes individual brain images for cross-subject and cross-study comparisons. Mask timeseries defines regions of interest, while spatial smoothing (6mm FWHM) reduces noise. Detrending with regressors accounts for temporal variations, and timing correction ensures accurate representation of brain activity dynamics. Manual ICA denoising identifies and removes non-neuronal sources of variability. These processes collectively improve the quality and integrity of fMRI data analysis. For this analysis, we utilized preprocessed functional files that had undergone blurring and remained uncensored. The term "blurred" pertains to fMRI images or time series data that have been subject to spatial smoothing or blurring via a filtering process, to increase signal and reduce noise. On the other hand, "uncensored" refers to fMRI data that has not undergone any exclusion or removal of time points or volumes due to artifacts. For our analysis, we divided each functional data file into three sections: Set-up, Development, and Resolution, using *fslroi* (Jenkinson et al., 2012). For *500 Days of Summer* (Webb, 2009) the film consisted of 5470 acquired volumes. The Set-up section of the film spanned volumes 1 – 1823, the Development section spanned volumes 1824 – 3647, and the Resolution section consisted of volumes 3648 – 5470. Because 5470 is not divisible by three, the Resolution section of the film consisted of one less volume than the Development and Resolution sections.

Data Analysis

Using the data files split into the Set-up, Development, and Resolution sections, we then calculated ISCs for each pair of subjects in the analysis. These pairings were formed across 20 participants within each film section (Set-up, Development, and Resolution), resulting in 190 unique pairings of participants per section. *3dtcorrelate* (Cox, 1996) was used to generate these ISC pairings for each film section. ISC is a model-free approach frequently used in tandem with naturalistic stimuli. ISC involves correlating neural responses between participants over the time course of a stimulus, producing results that highlight areas that show synchronous activity, as seen in Figure 2.1. This synchronization suggests these brain areas are collectively responding to the stimulus and identify consistent neural engagement across subjects during specific experiences.

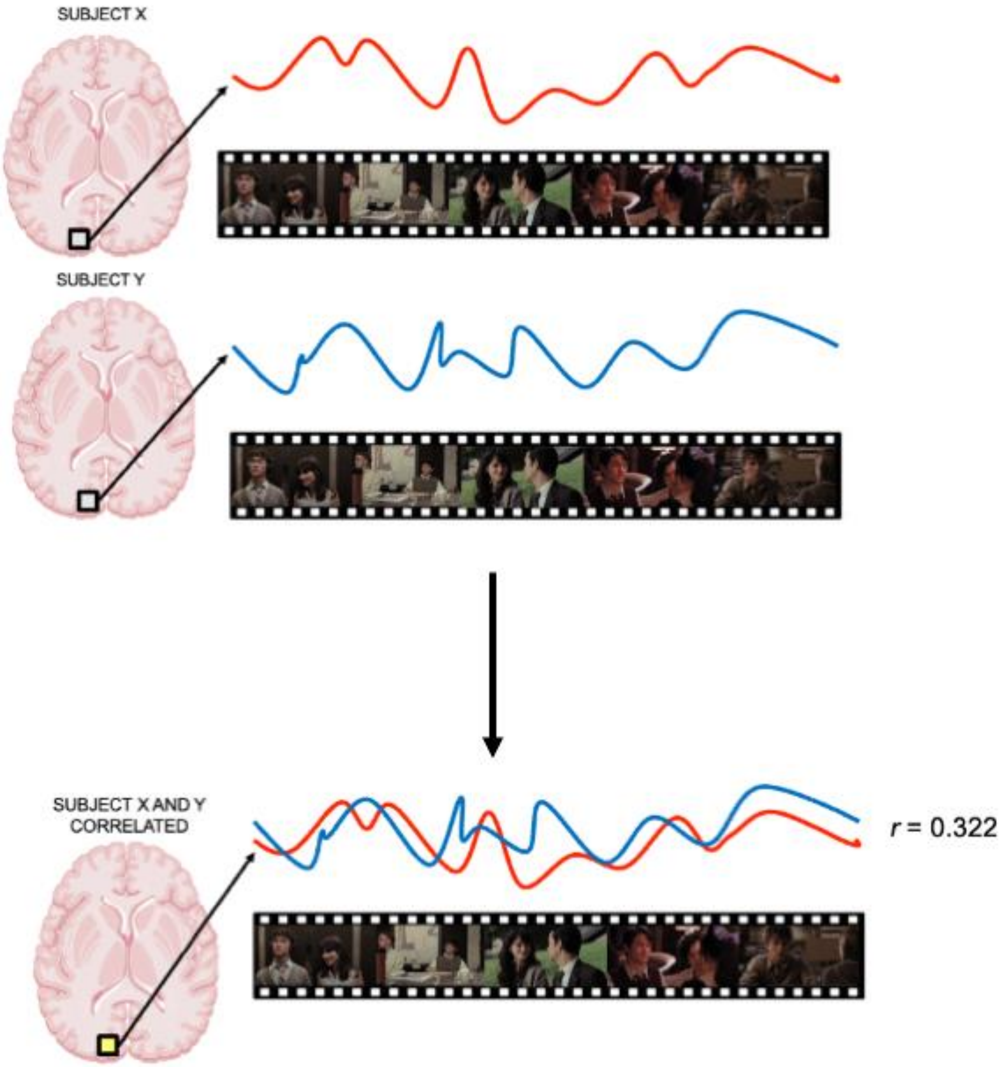


Figure 2.1. Intersubject Correlation Analysis. A schematic representation showcasing the ISC workflow for a single voxel. This process is repeated for all voxels in the brain and all pairs of participants in the analysis.

Next, we used linear mixed effects (LME) modelling implemented via the *3dISC* module in AFNI (Chen et al., 2017; Cox, 1996) to identify significant regions of neural synchrony, as quantified using ISC analysis. To do so, we ran an LME analysis for all 190 participant ISC pairings for each of the three film sections individually, resulting in three separate one-group analyses (Set-up, Development, and Resolution). LME modelling is a parametric method that assumes certain distributions of the data, such as normal or Gaussian distributions. This approach accounts for the complex covariance structure of ISC data and incorporates both random effects (e.g., variability in brain activity across participants) and fixed effects (e.g., effects of experimental conditions on brain activity) within the same model (Chen et al., 2017). This enables a more accurate estimation of fixed effects by accounting for data variability due to random effects (Koerner & Zhang, 2017). Significant ISC was determined using a voxel-wise false discovery rate (FDR) threshold of $q < 0.0001$ for each contrast. FDR is a statistical method to control the proportion of false positives (Benjamini & Hochberg, 1995). A critical threshold is determined by the desired FDR, in this case 0. 0001. The critical t values were 5.5987, 5.6036, and 5.8193 for Set-up, Development, and Resolution, respectively. These critical t values indicate that 0.01% of the voxels found to be significant, could be false discoveries. This method is validated by Chen and colleagues (Chen et al., 2017). *Using* these critical t-statistics, the resulting t-statistic image was thresholded using *fslmaths* '-thr' function (Jenkinson et al., 2012), at the aforementioned critical t value and the ISC image was masked using *fslmaths* '-mas' function (Jenkinson et al., 2012). TkSurfer (http://surfer.nmr.mgh.harvard.edu/fswiki) was used to create each of the figures, rendered for both the left and right hemispheres and in medial, lateral, and inferior orientation. This visualization is in surface space, which allows for a clear view of the cortical surface and is useful for showing functional patterns on the brain's surface.

2.3 Results

Set-up

Results from the one-way LME for the Set-up contrast found 33 significant clusters of neural synchrony across the brain (see Figure 2.2 and Table 2.1). In line with our hypotheses, we found significant neural synchrony in regions associated with visuospatial attention, including the right FEF, SPL, TPJ, and IFG/MFG. Further, we found significant neural synchrony in regions associated with episodic memory (bilateral precuneus, PHC, RSC, AG, PCC, and mPFC) and semantic memory (left temporal pole, ACC, fusiform gyrus, IPS, posterior MTG, and PFC). We also found significant clusters of neural synchrony in areas such as the bilateral precentral gyrus, bilateral frontal poles, and right temporal pole. In addition to these cortical areas, subcortical regions including the right thalamus, right amygdala, right caudate, and bilateral crus II in the cerebellum showed significant neural synchrony during this stage of the narrative.

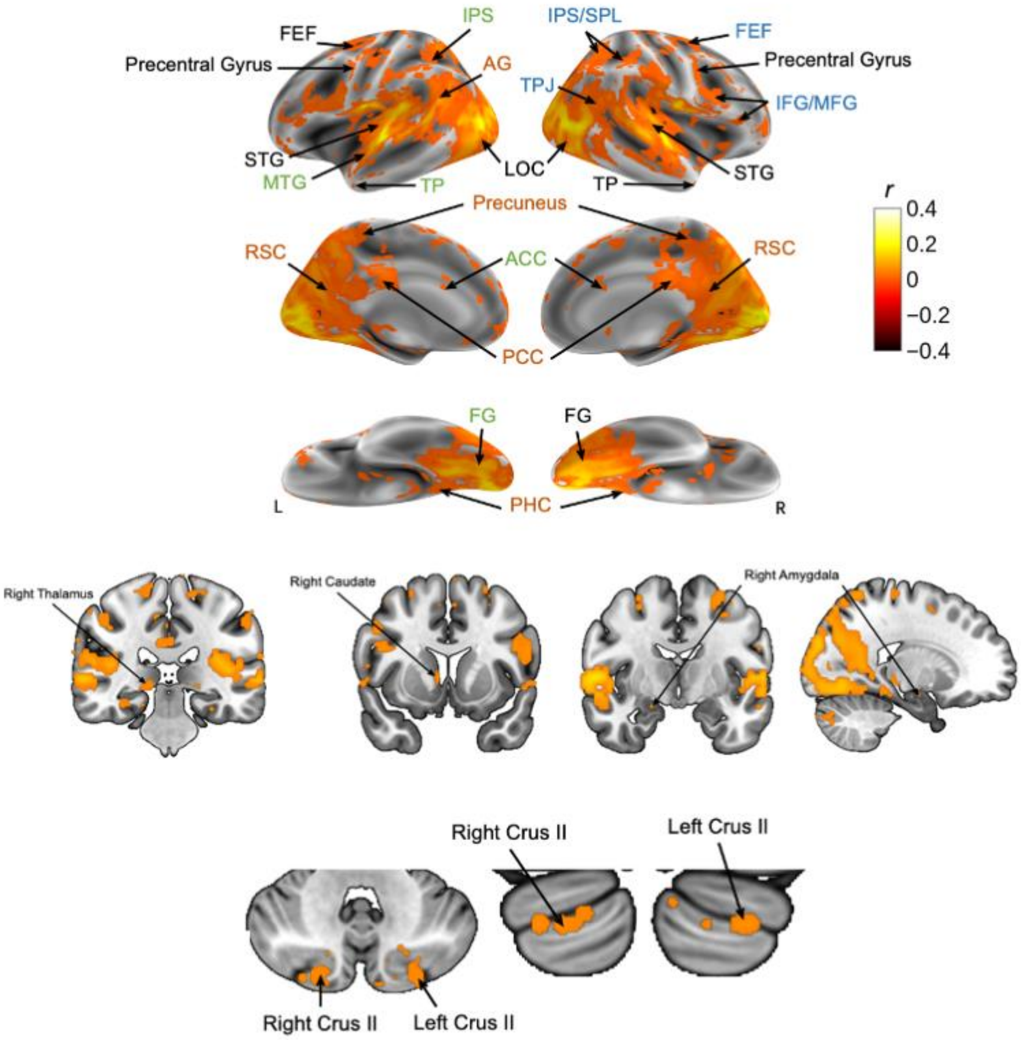
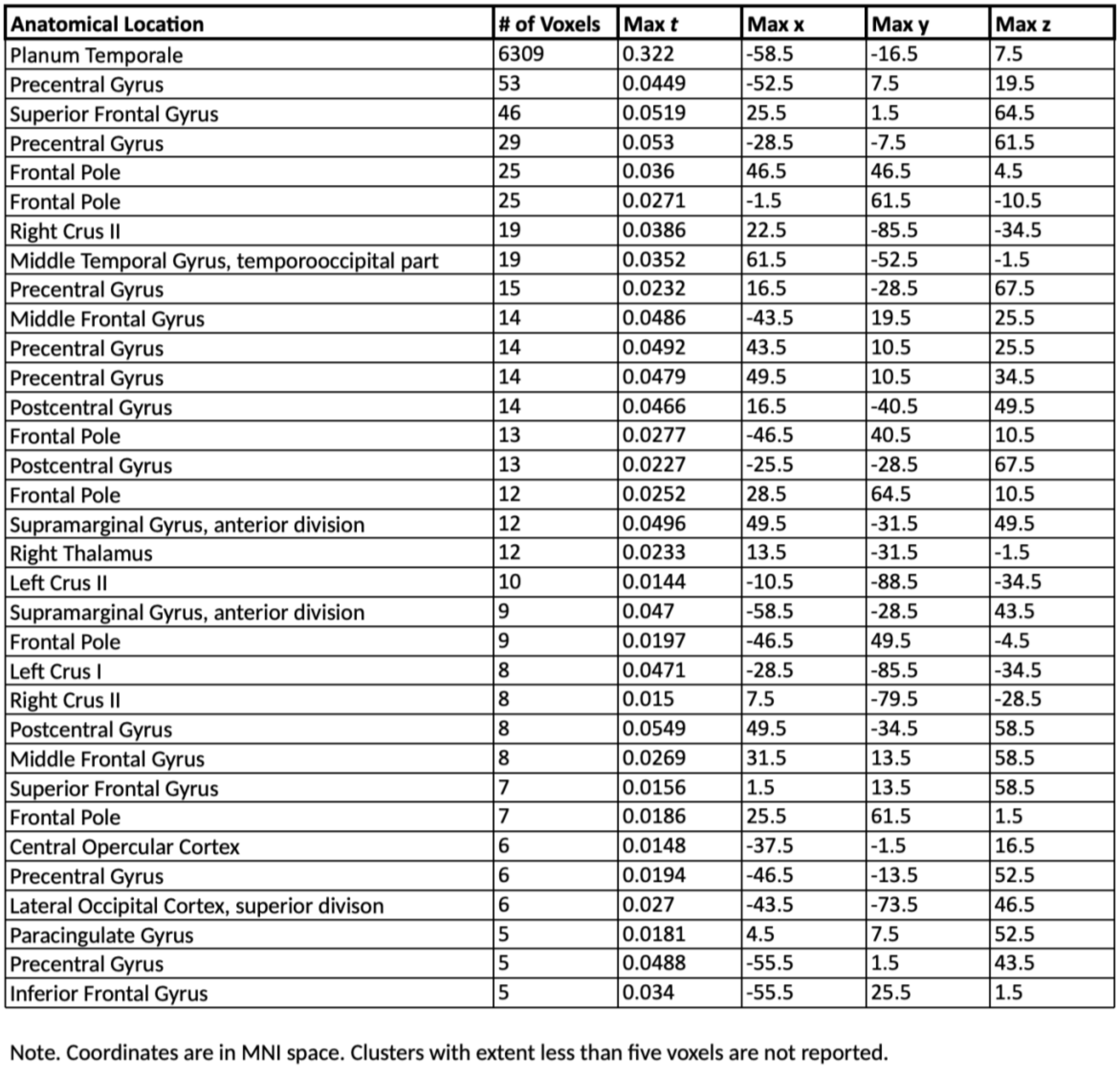


Figure 2.2. *500 Days of Summer*: Set-up Neural Synchrony. Synchrony maps derived from fMRI data during audiovisual movie watching. Maps are shown for the left (L) and right (R) hemispheres, in the lateral, medial, and inferior orientations. Areas in blue represent neural

correlates of visuospatial attention, areas in green represent neural correlates of semantic memory, and areas in orange represent neural correlates of episodic memory.

Table 2.1. *500 Days of Summer*: Set-up Cluster Table. Coordinates in MNI space. Only clusters with five or more voxels are reported.



Anatomical Location	# of Voxels	Max *t*	Max x	Max y	Max z
Planum Temporale	6309	0.322	-58.5	-16.5	7.5
Precentral Gyrus	53	0.0449	-52.5	7.5	19.5
Superior Frontal Gyrus	46	0.0519	25.5	1.5	64.5
Precentral Gyrus	29	0.053	-28.5	-7.5	61.5
Frontal Pole	25	0.036	46.5	46.5	4.5
Frontal Pole	25	0.0271	-1.5	61.5	-10.5
Right Crus II	19	0.0386	22.5	-85.5	-34.5
Middle Temporal Gyrus, temporooccipital part	19	0.0352	61.5	-52.5	-1.5
Precentral Gyrus	15	0.0232	16.5	-28.5	67.5
Middle Frontal Gyrus	14	0.0486	-43.5	19.5	25.5
Precentral Gyrus	14	0.0492	43.5	10.5	25.5
Precentral Gyrus	14	0.0479	49.5	10.5	34.5
Postcentral Gyrus	14	0.0466	16.5	-40.5	49.5
Frontal Pole	13	0.0277	-46.5	40.5	10.5
Postcentral Gyrus	13	0.0227	-25.5	-28.5	67.5
Frontal Pole	12	0.0252	28.5	64.5	10.5
Supramarginal Gyrus, anterior division	12	0.0496	49.5	-31.5	49.5
Right Thalamus	12	0.0233	13.5	-31.5	-1.5
Left Crus II	10	0.0144	-10.5	-88.5	-34.5
Supramarginal Gyrus, anterior division	9	0.047	-58.5	-28.5	43.5
Frontal Pole	9	0.0197	-46.5	49.5	-4.5
Left Crus I	8	0.0471	-28.5	-85.5	-34.5
Right Crus II	8	0.015	7.5	-79.5	-28.5
Postcentral Gyrus	8	0.0549	49.5	-34.5	58.5
Middle Frontal Gyrus	8	0.0269	31.5	13.5	58.5
Superior Frontal Gyrus	7	0.0156	1.5	13.5	58.5
Frontal Pole	7	0.0186	25.5	61.5	1.5
Central Opercular Cortex	6	0.0148	-37.5	-1.5	16.5
Precentral Gyrus	6	0.0194	-46.5	-13.5	52.5
Lateral Occipital Cortex, superior divison	6	0.027	-43.5	-73.5	46.5
Paracingulate Gyrus	5	0.0181	4.5	7.5	52.5
Precentral Gyrus	5	0.0488	-55.5	1.5	43.5
Inferior Frontal Gyrus	5	0.034	-55.5	25.5	1.5

Note. Coordinates are in MNI space. Clusters with extent less than five voxels are not reported.

Development

Results from the one-way LME for the Development contrast found 38 significant clusters of neural synchrony (see Figure 2.3 and Table 2.2). In line with our hypotheses, we found significant synchrony in regions associated with visuospatial attention, namely the right FEF, SPL, TPJ, and IFG/MFG. Additionally, regions involved in episodic memory exhibited neural synchronization, particularly in the bilateral precuneus, PHC, RSC, AG, PCC, and mPFC. We found significant clusters of neural synchrony in the following semantic memory areas (left-lateralized): temporal pole, fusiform gyrus, IPS, posterior MTG, and PFC. Other areas that showed significant neural synchrony were the bilateral precentral gyrus, bilateral frontal poles, and right temporal pole, as seen in Figure 2.3. Further, subcortical areas with significant clusters of neural synchrony during the Development section include the right hippocampus and the bilateral crus II in the cerebellum.

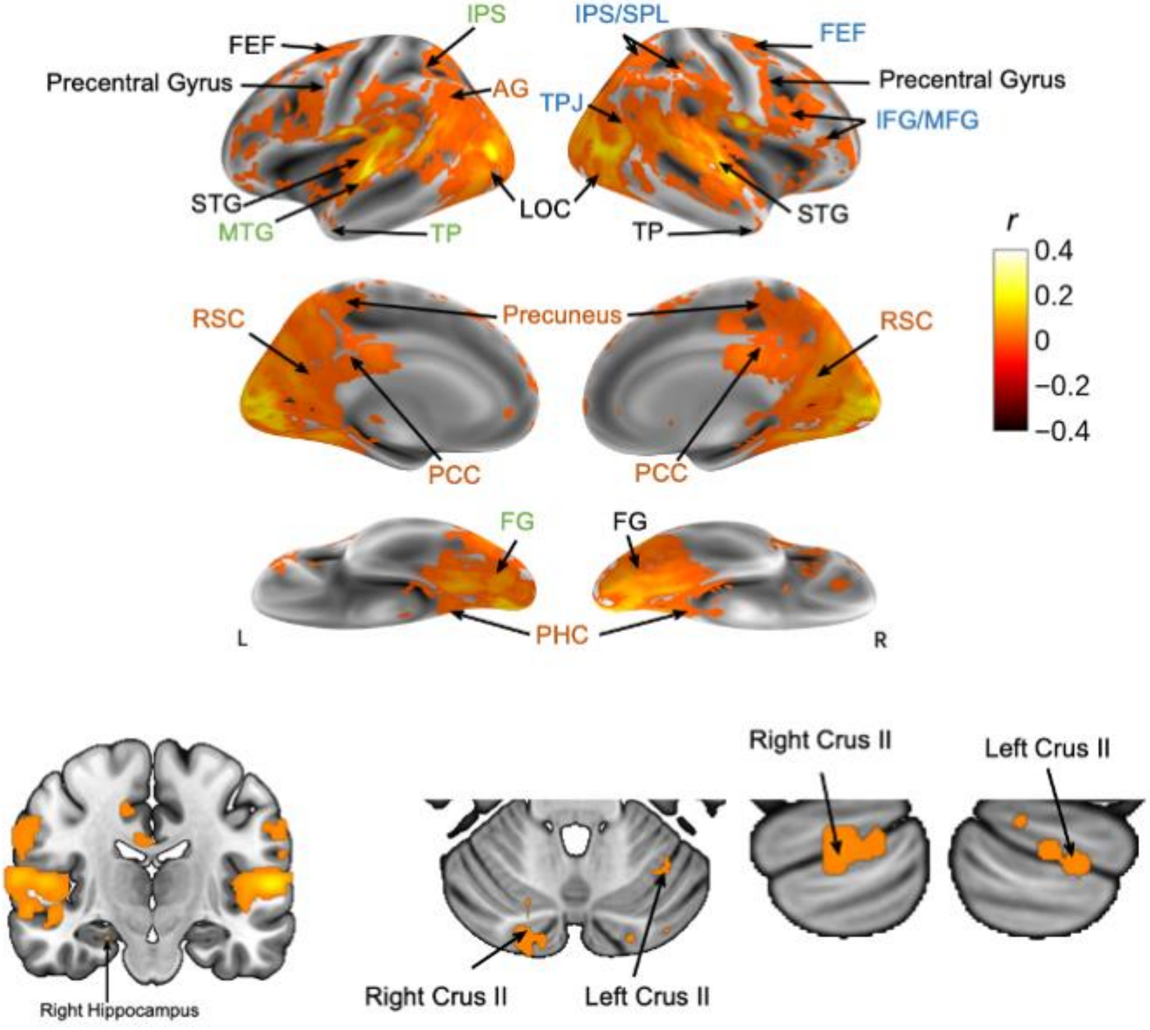
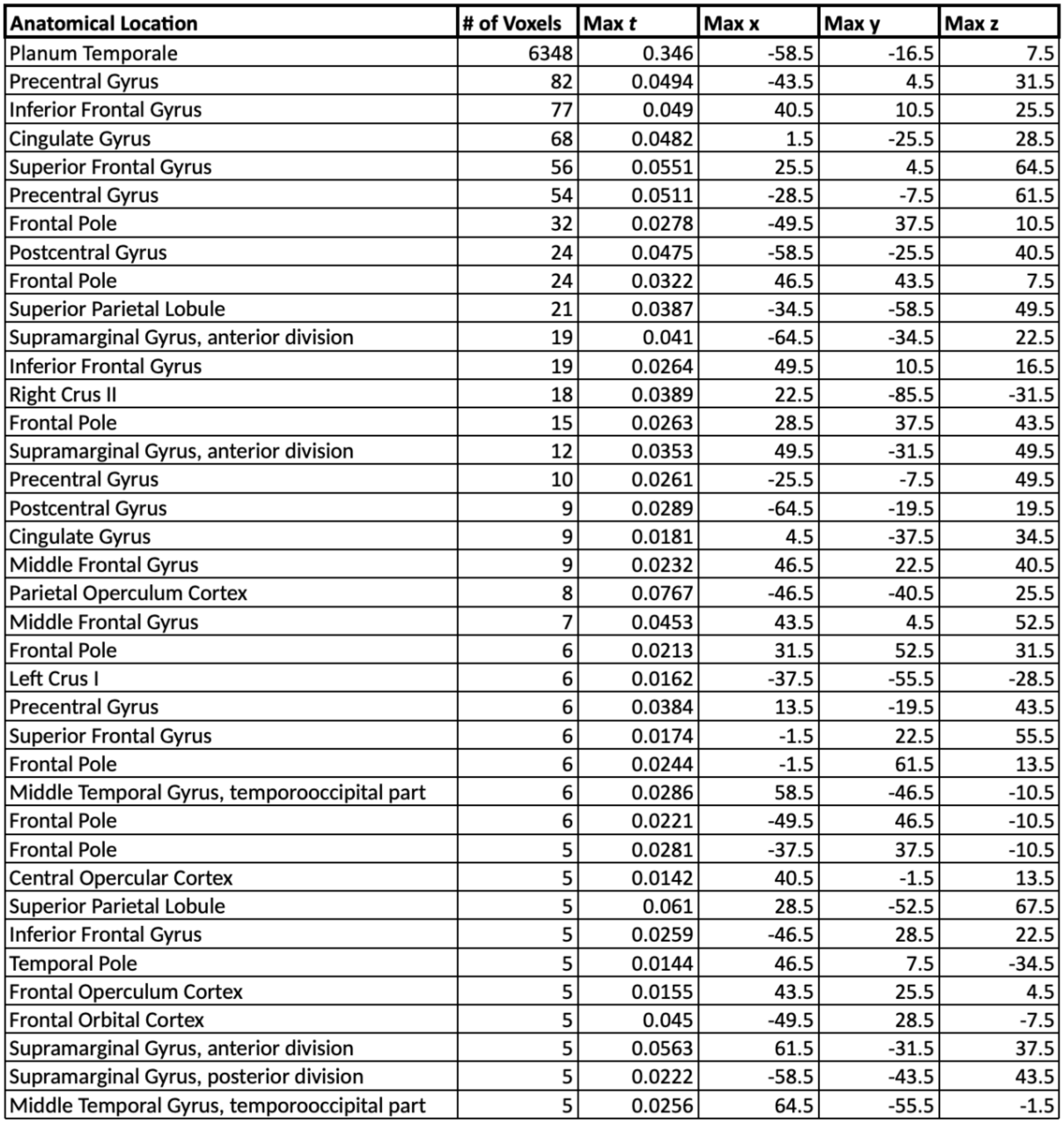


Figure 2.3. *500 Days of Summer*: Development Neural Synchrony. Synchrony maps derived from fMRI data during audiovisual movie watching. Maps are shown for the left (L) and right (R) hemispheres, in the lateral, medial, and inferior orientations. Areas in blue represent neural correlates of visuospatial attention, areas in green represent neural correlates of semantic memory, and areas in orange represent neural correlates of episodic memory.

Table 2.2. *500 Days of* Summer: Development Cluster Table. Coordinates in MNI space. Only clusters with five or more voxels are reported.



Anatomical Location	**# of Voxels**	**Max *t***	**Max x**	**Max y**	**Max z**
Planum Temporale	6348	0.346	-58.5	-16.5	7.5
Precentral Gyrus	82	0.0494	-43.5	4.5	31.5
Inferior Frontal Gyrus	77	0.049	40.5	10.5	25.5
Cingulate Gyrus	68	0.0482	1.5	-25.5	28.5
Superior Frontal Gyrus	56	0.0551	25.5	4.5	64.5
Precentral Gyrus	54	0.0511	-28.5	-7.5	61.5
Frontal Pole	32	0.0278	-49.5	37.5	10.5
Postcentral Gyrus	24	0.0475	-58.5	-25.5	40.5
Frontal Pole	24	0.0322	46.5	43.5	7.5
Superior Parietal Lobule	21	0.0387	-34.5	-58.5	49.5
Supramarginal Gyrus, anterior division	19	0.041	-64.5	-34.5	22.5
Inferior Frontal Gyrus	19	0.0264	49.5	10.5	16.5
Right Crus II	18	0.0389	22.5	-85.5	-31.5
Frontal Pole	15	0.0263	28.5	37.5	43.5
Supramarginal Gyrus, anterior division	12	0.0353	49.5	-31.5	49.5
Precentral Gyrus	10	0.0261	-25.5	-7.5	49.5
Postcentral Gyrus	9	0.0289	-64.5	-19.5	19.5
Cingulate Gyrus	9	0.0181	4.5	-37.5	34.5
Middle Frontal Gyrus	9	0.0232	46.5	22.5	40.5
Parietal Operculum Cortex	8	0.0767	-46.5	-40.5	25.5
Middle Frontal Gyrus	7	0.0453	43.5	4.5	52.5
Frontal Pole	6	0.0213	31.5	52.5	31.5
Left Crus I	6	0.0162	-37.5	-55.5	-28.5
Precentral Gyrus	6	0.0384	13.5	-19.5	43.5
Superior Frontal Gyrus	6	0.0174	-1.5	22.5	55.5
Frontal Pole	6	0.0244	-1.5	61.5	13.5
Middle Temporal Gyrus, temporooccipital part	6	0.0286	58.5	-46.5	-10.5
Frontal Pole	6	0.0221	-49.5	46.5	-10.5
Frontal Pole	5	0.0281	-37.5	37.5	-10.5
Central Opercular Cortex	5	0.0142	40.5	-1.5	13.5
Superior Parietal Lobule	5	0.061	28.5	-52.5	67.5
Inferior Frontal Gyrus	5	0.0259	-46.5	28.5	22.5
Temporal Pole	5	0.0144	46.5	7.5	-34.5
Frontal Operculum Cortex	5	0.0155	43.5	25.5	4.5
Frontal Orbital Cortex	5	0.045	-49.5	28.5	-7.5
Supramarginal Gyrus, anterior division	5	0.0563	61.5	-31.5	37.5
Supramarginal Gyrus, posterior division	5	0.0222	-58.5	-43.5	43.5
Middle Temporal Gyrus, temporooccipital part	5	0.0256	64.5	-55.5	-1.5

Note. Coordinates are in MNI space. Clusters with extent less than five voxels are not reported.

Resolution

Results from the one-way LME for the Resolution contrast found 22 significant clusters of neural synchrony (see Figure 2.4. and Table 2.3). Visuospatial attention areas, specifically the right FEF, SPL, TPJ, and IFG/MFG, showed significant synchronous activity. Moreover, regions associated with episodic memory demonstrated neural synchronization, particularly in the bilateral precuneus, PHC, RSC, AG, PCC, and mPFC. Significant semantic memory areas included the left temporal pole, fusiform gyrus, IPS, and PFC. Other areas that showed significant clusters of neural synchrony were the precentral gyrus, bilateral frontal poles, and right temporal pole, as seen in Figure 2.4. Subcortical areas with neural synchrony during the Resolution section include the bilateral caudate and the bilateral crus II in the cerebellum.

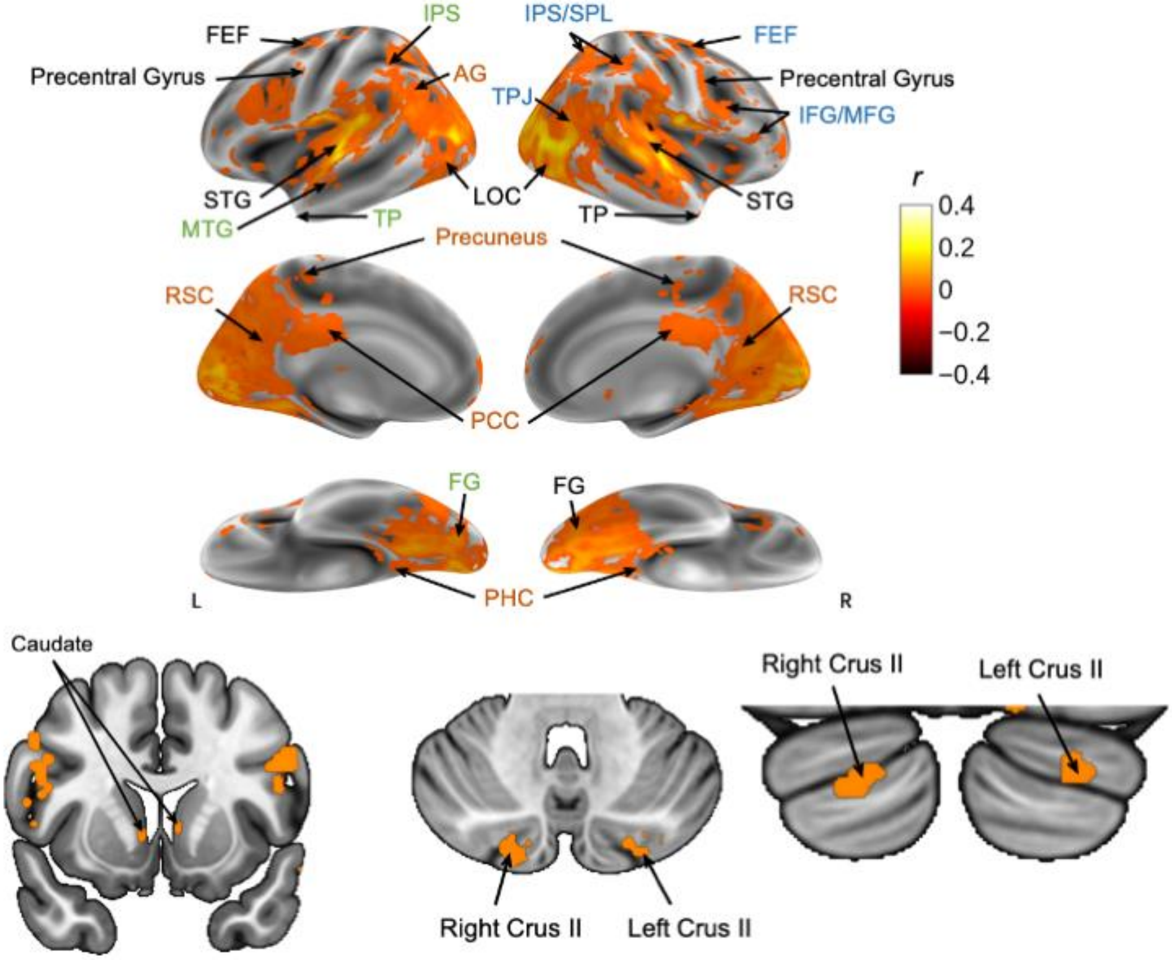
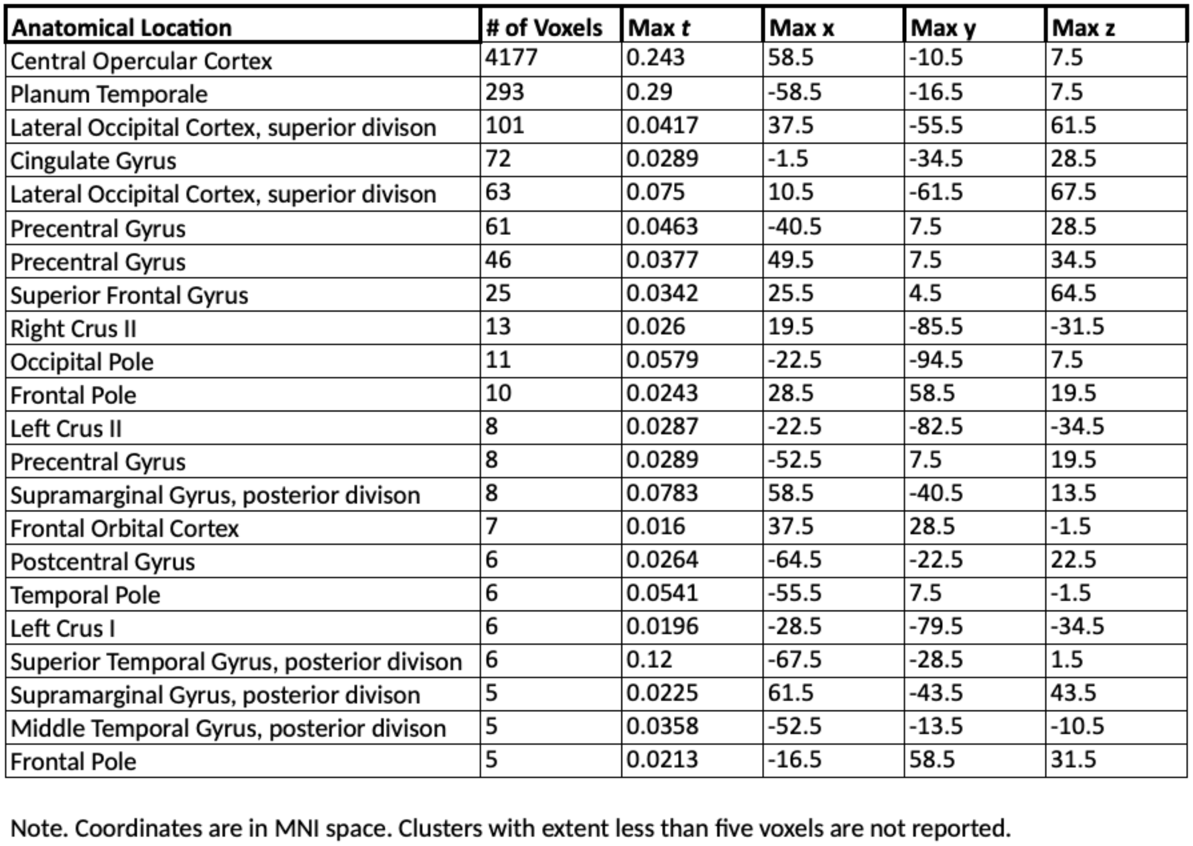


Figure 2.4. *500 Days of* Summer: Resolution Neural Synchrony. Synchrony maps derived from fMRI data during audiovisual movie watching. Maps are shown for the left (L) and right (R) hemispheres, in the lateral, medial, and inferior orientations. Areas in blue represent neural correlates of visuospatial attention, areas in green represent neural correlates of semantic memory, and areas in orange represent neural correlates of episodic memory.

Table 2.3. *500 Days of* Summer: Resolution Cluster Table. Coordinates in MNI space. Only clusters with five or more voxels are reported.



Anatomical Location	# of Voxels	Max *t*	Max x	Max y	Max z
Central Opercular Cortex	4177	0.243	58.5	-10.5	7.5
Planum Temporale	293	0.29	-58.5	-16.5	7.5
Lateral Occipital Cortex, superior divison	101	0.0417	37.5	-55.5	61.5
Cingulate Gyrus	72	0.0289	-1.5	-34.5	28.5
Lateral Occipital Cortex, superior divison	63	0.075	10.5	-61.5	67.5
Precentral Gyrus	61	0.0463	-40.5	7.5	28.5
Precentral Gyrus	46	0.0377	49.5	7.5	34.5
Superior Frontal Gyrus	25	0.0342	25.5	4.5	64.5
Right Crus II	13	0.026	19.5	-85.5	-31.5
Occipital Pole	11	0.0579	-22.5	-94.5	7.5
Frontal Pole	10	0.0243	28.5	58.5	19.5
Left Crus II	8	0.0287	-22.5	-82.5	-34.5
Precentral Gyrus	8	0.0289	-52.5	7.5	19.5
Supramarginal Gyrus, posterior divison	8	0.0783	58.5	-40.5	13.5
Frontal Orbital Cortex	7	0.016	37.5	28.5	-1.5
Postcentral Gyrus	6	0.0264	-64.5	-22.5	22.5
Temporal Pole	6	0.0541	-55.5	7.5	-1.5
Left Crus I	6	0.0196	-28.5	-79.5	-34.5
Superior Temporal Gyrus, posterior divison	6	0.12	-67.5	-28.5	1.5
Supramarginal Gyrus, posterior divison	5	0.0225	61.5	-43.5	43.5
Middle Temporal Gyrus, posterior divison	5	0.0358	-52.5	-13.5	-10.5
Frontal Pole	5	0.0213	-16.5	58.5	31.5

Note. Coordinates are in MNI space. Clusters with extent less than five voxels are not reported.

2.4 Discussion

Results from Experiment 1 provide valuable insight into the neural correlates of narrative processing, highlighting diverse cognitive processes that contribute to processing. Significant neural synchrony was observed in attentional areas, including the areas of the dorsal (right FEF and SPL) and ventral (right TPJ and IFG/MFG) attention networks across all three sections of the film. This suggests that both goal-driven attention and stimulus-driven attention are being utilized across the narrative. According to Jääskeläinen et al. (2020), the TPJ, IPS, and FEF are involved in narrative engagement and arousal. Episodic memory areas showed consistent bilateral synchrony across all three narrative sections, including the precuneus, PHC, RSC, AG, PCC, and mPFC. This suggests narrative processing requires significant episodic memory system recruitment to parse and encode important episodic narrative information. In addition, the precuneus is involved in narrative interpretation, highlighting its role in connecting narrative elements and interlacing them into a coherent representation (Jääskeläinen et al., 2020). The right hippocampus, an area known to be involved in episodic memory, showed significant neural synchrony during the Development portion of the film. This finding mirrors the results of Tylén et al., 2015 who found the right hippocampus to be involved in plot formation (Tylén et al., 2015).

However, several semantic memory regions did not show significant synchrony across the three sections. Regions consistently synchronized across all film sections included the left temporal pole, fusiform gyrus, IPS and PFC. The left ACC was synchronized during only the Set-up portion, and the MTG remained synchronous during Set-up and Development but not Resolution. This suggests that the brain's semantic memory regions are dynamically engaged and synchronized during narrative progression, but the involvement changes over the course of the narrative. This conclusion is supported by the findings of Jääskeläinen et al., 2020, who found that the synchronous activity in the TPJ, IPS, and FEF are based on the attentional engagement of a narrative. Moreover, a more attentionally engaging film would result in more synchronous activity in these regions. Therefore, changes in synchronous activity in these areas would suggest changes in engagement with narrative relevant content. Additionally, during Set-up, there may be more concerted efforts to establish the narrative's context and characters, requiring greater synchronous activation within the semantic memory network. As the story progresses, there could be a shift in focus towards more detailed and context-specific processing, leading to reduced synchrony within this network. Thus, while attentional and episodic memory regions remain synchronized across Set-up, Development, and Resolution, neural synchrony in semantic regions (specifically the left ACC and MTG) changes as the narrative progresses.

Together, results from Experiment 1 provide evidence of neural synchrony in the visuospatial attention system (both in the dorsal and ventral attentional networks), the semantic memory system (hubs: temporal pole, ACC, peripheral: MTG, IPS, ACC), and the episodic memory system (precuneus, PCC, AG, and mPFC) for the Set-up, Development, and Resolution phases of a complex audiovisual movie. Further, the study revealed a gradual decline in the engagement of semantic memory areas as the narrative unfolded. This observation is substantiated by the diminishing presence of synchronous activity within semantic regions as the narrative progressed. In the initial Set-up phase, all the regions previously highlighted for their relevance to semantic memory exhibited synchronized activity. However, during the Development portion, the left ACC did not show significant synchronous activity. During the Resolution phase, both the left ACC and MTG exhibited an absence of significant synchronous activity. These patterns of diminishing synchrony suggest a modulation in the cognitive demands associated with semantic memory processing throughout the narrative progression.

However, one limitation of this experiment is that, although it demonstrates consistent regions with patterns of neural synchrony throughout a narrative, it does not provide information about differences in neural synchrony across the narrative. Further, because the participants were viewing the same stimulus, we observed a large amount of neural synchrony in auditory and visual areas that is likely related to processing specific aspects of the stimulus itself rather than overall narrative processing. Thus, future research is necessary to disentangle the changing cognitive demands over the course of a narrative.

In summary, the findings from Experiment 1 present evidence of neural synchrony within different cognitive systems during the distinct phases of a complex audiovisual narrative. These results demonstrate synchronized activity within the visuospatial attention system (both dorsal and ventral networks), semantic memory system, and episodic memory system throughout the Set-up, Development, and Resolution stages of the narrative. Notably, as the narrative unfolds there is a reduction in the involvement of semantic memory brain regions. Overall, this study offers crucial insights into how the brain integrates information about narrative structure and plot progression into long-term memory, revealing distinct synchrony patterns that mirror cognitive shifts and emotional engagement across the narrative acts. While the findings provide an overview of neural synchrony within specific cognitive systems during the individual phases of the audiovisual narrative—ranging from Set-up to Development and Resolution—there remains a gap in our understanding when it comes to direct inter-section comparisons, which will be examined in the following experiment.

Experiment 2

3.1 Introduction

Narratives undergo constant evolution, continually presenting new information to readers, listeners, or viewers. While Experiment 1 revealed significant neural synchrony within specific sections of the narrative, it did not examine how synchrony differs across the three parts of the narrative. The objective of Experiment 2 was to identify differences in neural synchrony across the three sections of the film, shedding light on the shifting cognitive demands throughout the narrative. Thus, Experiment 2 aimed to identify patterns of neural synchrony for each distinct film section through the following comparisons: Set-up vs. Development, Set-up vs. Resolution, and Development vs. Resolution. The overall hypothesis was that evolving cognitive demands inherent to the narrative would give rise to dynamic alterations in neural synchrony within the attentional, semantic, and episodic networks. The specific hypotheses for each contrast are outlined below.

Set-up vs. Development

This comparison aimed to assess variations in neural synchrony between the Set-up and Development sections of *500 Days of Summer* (Webb, 2009). We hypothesized that regions associated with goal-directed attention would exhibit greater synchrony during the Set-up than the Development phase, attributed to the influx of plot-relevant information necessitating focused attention. Further, semantic memory areas would show greater synchrony during the Set-up phase compared to Development. Similar to goal-directed attention, this would be due to the influx of new plot-relevant information, requiring a solid semantic structure to build forthcoming narrative elements. Conversely, we hypothesized that episodic memory areas would show greater synchrony in the Development than the Set-up phase due to an increase in information being integrated and updated into long-term memory as the narrative progresses. We also hypothesized that there would be more involvement of stimulus-driven visuospatial attention areas in Development compared to Set-up, as sensory components of the evolving plot become dominant.

Set-up vs. Resolution

This contrast sought to identify differences in neural synchrony between the Set-up and Resolution portion of *500 Days of Summer* (Webb, 2009). We hypothesized that regions involved in goal-directed attention would be more synchronous during Set-up, and regions involved in stimulus-directed attention would be more synchronous during the Resolution phase. This shift in visuospatial attention demands would arise from the evolving cognitive requirements tied to attention. Specifically, in the Set-up phase, there is a need to focus attention on plot-relevant elements of the narrative, which aids in constructing a coherent and cohesive narrative representation. As the film progresses, less goal-directed visuospatial attention is necessary, and there is greater reliance on stimulus-driven attention as the viewer processes the unfolding plot. Additionally, areas involved in semantic memory would be more synchronous during Set-up than Resolution due to the influx of new plot-relevant information, building a solid semantic structure for upcoming narrative elements.

Development vs. Resolution

This contrast aimed to uncover differences in neural synchrony between the Development and Resolution sections. We hypothesized that regions involved in goal-directed attention would be more synchronous during the Development of the narrative, and regions involved in stimulus-directed attention would be more synchronous during the Resolution phase. Changes in visuospatial attention demands stems from the changing demands associated with focus. Specifically, during the Development phase, viewers must concentrate on narrative-relevant components to create a logical and unified narrative. As the film advances, we hypothesized greater involvement of brain regions involved in stimulus-driven attention. Finally, we hypothesized that areas involved in semantic memory would show more synchronous activity during Development than Resolution, while areas involved in episodic memory would be more synchronous during Resolution than Development.

3.2 Methods

The methods for Experiment 2 were the same as Experiment 1, with the following exceptions.

Data Analysis

ISC pairings from Experiment 1 were used for this experiment across each film section. To examine differences in paired ISCs, we subtracted the corresponding ISC pairings for each pair of participants for each contrast of interest. Specifically, in the Set-up vs. Development contrast, each of the 190 pairings from the Set-up section was subtracted from its corresponding pair in the Development section using the *fslmaths* '-sub' (Jenkinson et al., 2012) command. This subtraction process was repeated for the Set-up vs. Resolution contrast and the Development vs. Resolution contrast. The resulting subtracted files were analyzed using a one-way LME using the *3dISC* module from AFNI (Chen et al., 2017; Cox, 1996) for each contrast, Set-up > Development, Development > Set-up, Set-up > Resolution, Resolution > Set-up, Development > Resolution, and Resolution > Development, which is equivalent to a series of paired sample *t*-tests. Significant ISC was determined using a voxel-wise FDR threshold of $q < .05$ for each contrast. The critical *t*-value was determined as 4.4804 for Set-up vs. Development, 3.2629 for Set-up vs. Resolution, and 3.5298 for Development vs. Resolution. To account for potential bidirectional synchrony in each contrast, thresholding was performed twice. This means that each contrast could exhibit significant differences in both directions (e.g., Set-up > Development and Development > Set-up for the Set-up vs. Development contrast). Using the critical t-stats, the t-stat image was thresholded using the *fslmaths* ‘-thr' and '-uthr' functions (Jenkinson et al., 2012) at the respective positive and negative critical *t*-values. We then masked the ISC image with the absolute value of the corresponding thresholded *t*-statistic image using the *fslmaths* ‘-mas' function (Jenkinson et al., 2012).

3.3 Results

Set-up vs. Development

Set-up > Development. Results from the one-way LME for the Set-up > Development contrast found 11 significant clusters of neural synchrony (see Figure 2.5 and Table 2.4), including the right SPL (a dorsal visuospatial attention area), the left precuneus and AG (episodic memory regions), and the left fusiform gyrus and IPS (semantic memory areas). Other regions that showed significant neural synchrony were the left supramarginal gyrus, bilateral precentral gyrus, occipital poles, occipital fusiform gyrus, and left precuneus.

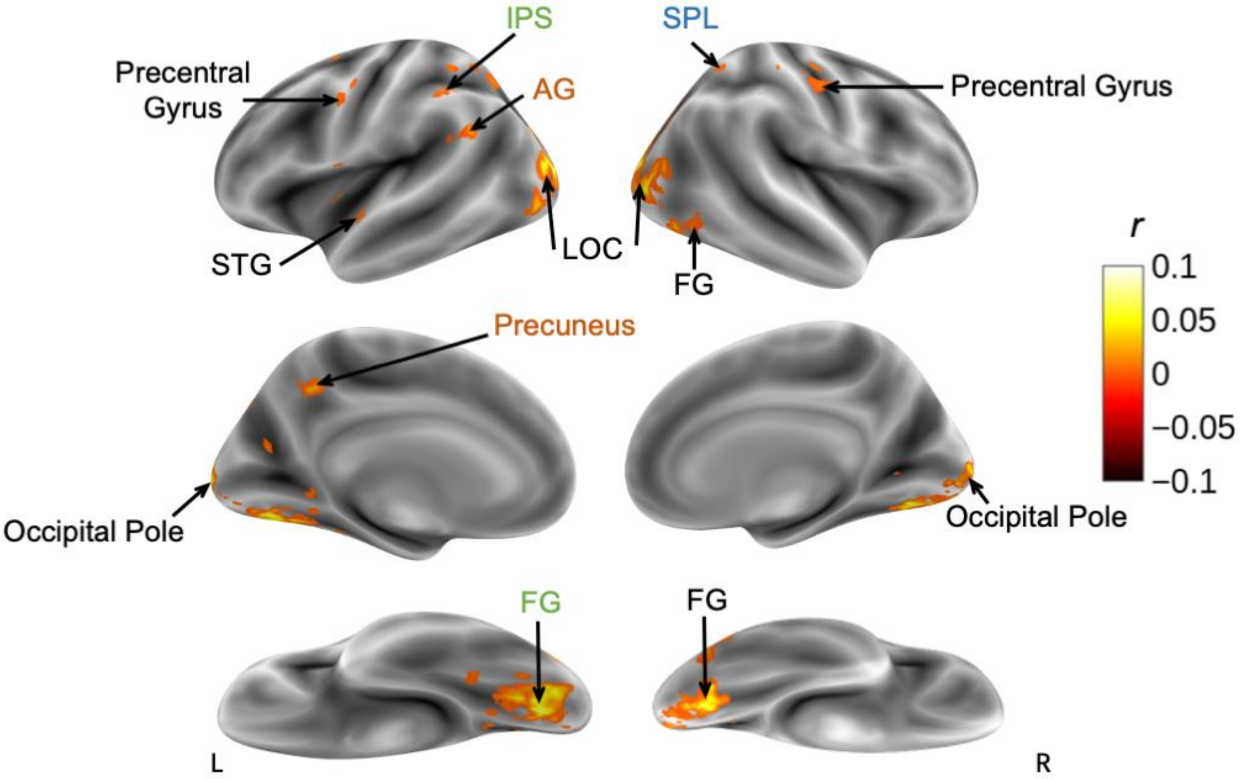


Figure 2.5. *500 Days of* Summer: Set-up > Development Synchrony. Synchrony maps derived from fMRI data during audiovisual movie watching. Maps are shown for the left (L) and right (R) hemispheres, in the lateral, medial, and inferior orientations. Areas in blue represent neural correlates of visuospatial attention, areas in green represent neural correlates of semantic memory, and areas in orange represent neural correlates of episodic memory.

Table 2.4. *500 Days of* Summer: Set-up > Development Cluster Table. Coordinates in MNI space. Only clusters with five or more voxels are reported.

Anatomical Location	**# of Voxels**	**Max *t***	**Max x**	**Max y**	**Max z**
Occipital Pole	86	0.0562	28.5	-91.5	13.5
Occipital Pole	73	0.0549	-25.5	-97.5	13.5
Occipital Fusiform Gyrus	56	0.0437	-25.5	-73.5	-7.5
Occipital Pole	23	0.0502	25.5	-73.5	-13.5
Occipital Pole	17	0.0465	-10.5	-100	13.5
Occipital Pole	12	0.0515	7.5	-91.5	4.5
Lateral Occipital Cortex, superior divison	9	0.0271	34.5	-58.5	58.5
Lateral Occipital Cortex, inferior divison	9	0.0447	-49.5	-76.5	-1.5
Lingual Gyrus	8	0.0262	13.5	-85.5	-7.5
Lateral Occipital Cortex, inferior divison	5	0.0257	46.5	-67.5	-7.5
Supramarginal Gyrus, posterior divison	5	0.0195	-46.5	-46.5	55.5

Note. Coordinates are in MNI space. Clusters with extent less than five voxels are not reported.

Development > Set-up. Results from the one-way LME for the Development > Set-up contrast found 18 significant clusters of neural synchrony (see Figure 2.6. and Table 2.5, including the right IFG/MFG (a visuospatial attention area), and the left AG (an episodic memory area) demonstrated neural synchronization. Other regions that showed significant neural synchrony were the left IFG, right MFG, right temporal pole and areas of the bilateral planum temporale, and left crus II as seen in Figure 2.6.

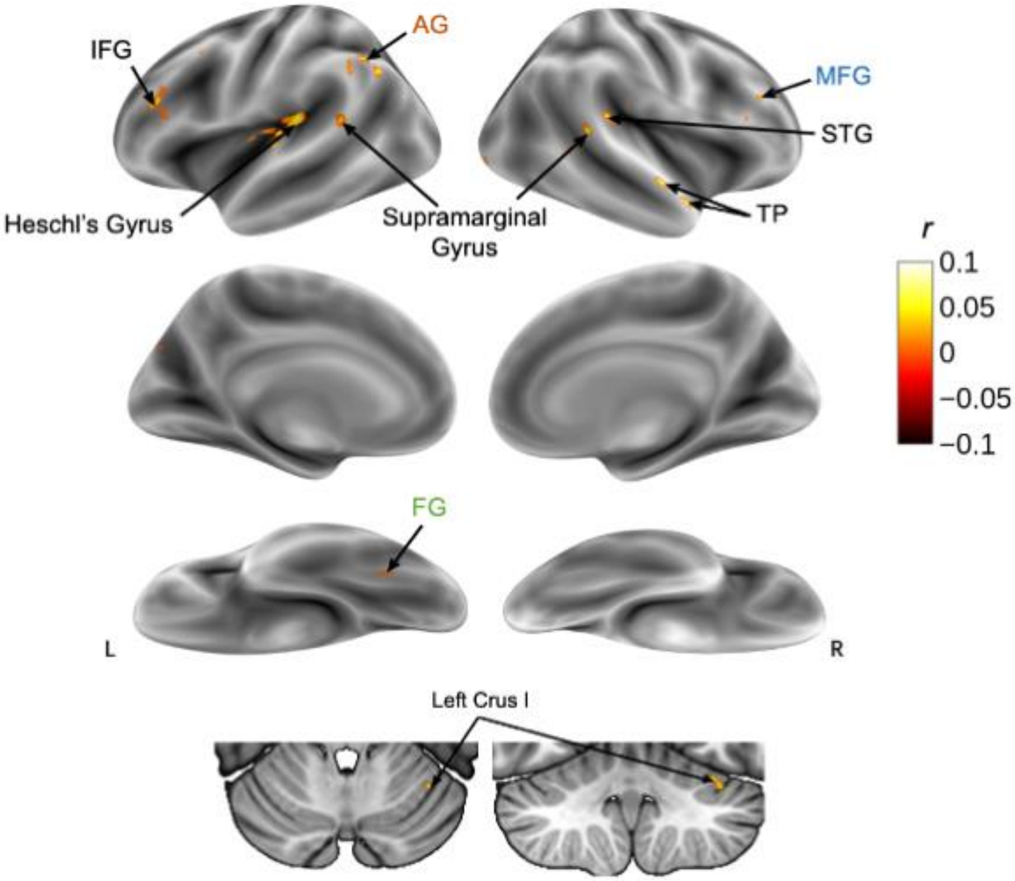
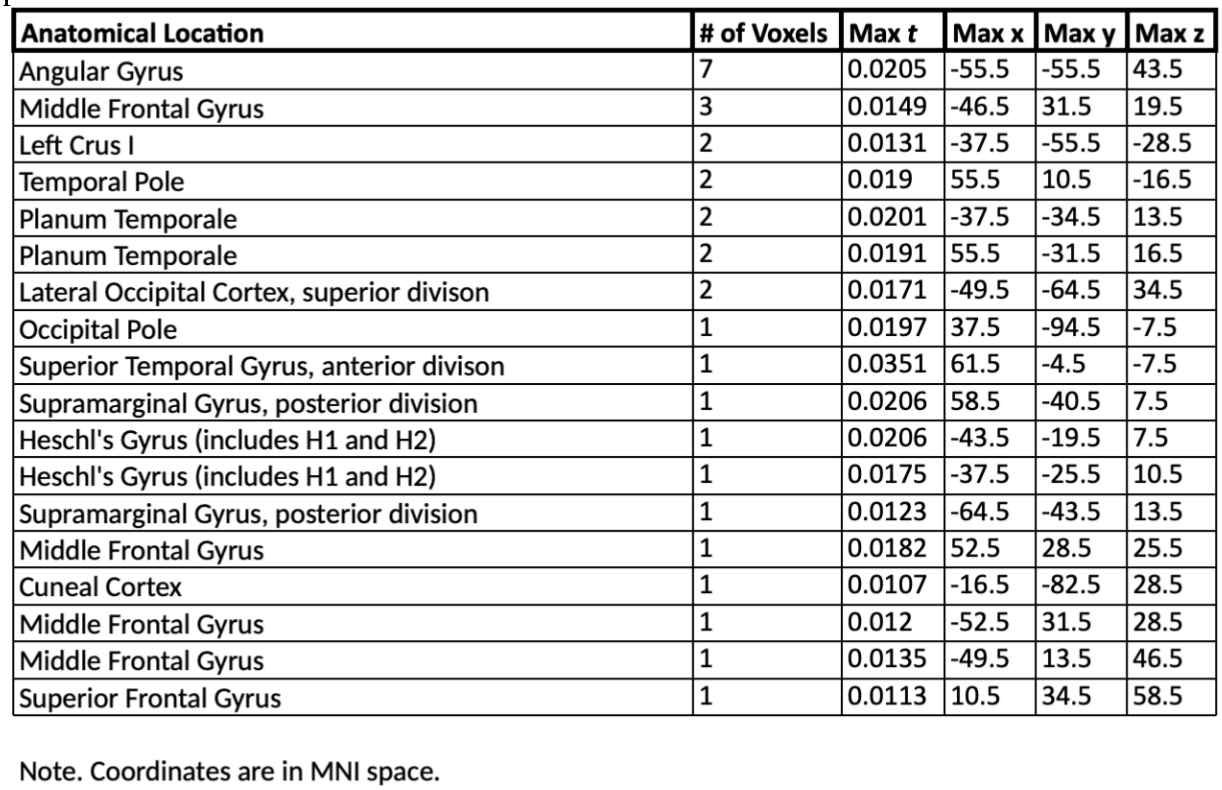


Figure 2.6. *500 Days of Summer*: Development > Set-up Synchrony. Synchrony maps derived from fMRI data during audiovisual movie watching. Maps are shown for the left (L) and right (R) hemispheres, in the lateral, medial, and inferior orientations. Areas in blue represent neural correlates of visuospatial attention, areas in green represent neural correlates of semantic memory, and areas in orange represent neural correlates of episodic memory.

Table 2.5. *500 Days of Summer:* Development > Set-up Cluster Table. Coordinates in MNI space.



Anatomical Location	# of Voxels	Max *t*	Max x	Max y	Max z
Angular Gyrus	7	0.0205	-55.5	-55.5	43.5
Middle Frontal Gyrus	3	0.0149	-46.5	31.5	19.5
Left Crus I	2	0.0131	-37.5	-55.5	-28.5
Temporal Pole	2	0.019	55.5	10.5	-16.5
Planum Temporale	2	0.0201	-37.5	-34.5	13.5
Planum Temporale	2	0.0191	55.5	-31.5	16.5
Lateral Occipital Cortex, superior divison	2	0.0171	-49.5	-64.5	34.5
Occipital Pole	1	0.0197	37.5	-94.5	-7.5
Superior Temporal Gyrus, anterior divison	1	0.0351	61.5	-4.5	-7.5
Supramarginal Gyrus, posterior division	1	0.0206	58.5	-40.5	7.5
Heschl's Gyrus (includes H1 and H2)	1	0.0206	-43.5	-19.5	7.5
Heschl's Gyrus (includes H1 and H2)	1	0.0175	-37.5	-25.5	10.5
Supramarginal Gyrus, posterior division	1	0.0123	-64.5	-43.5	13.5
Middle Frontal Gyrus	1	0.0182	52.5	28.5	25.5
Cuneal Cortex	1	0.0107	-16.5	-82.5	28.5
Middle Frontal Gyrus	1	0.012	-52.5	31.5	28.5
Middle Frontal Gyrus	1	0.0135	-49.5	13.5	46.5
Superior Frontal Gyrus	1	0.0113	10.5	34.5	58.5

Note. Coordinates are in MNI space.

Set-up vs. Resolution

Set-up > Resolution.

Results from the one-way LME for the Set-up > Resolution contrast identified 43 significant clusters of neural synchrony (see Figure 2.7 and Table 2.6), including the right FEF, SPL, and TPJ (visuospatial attention areas), and the bilateral mPFC, precuneus, PHC, RSC, AG, and PCC (episodic memory areas). Semantic memory areas including the hubs of the left temporal pole and ACC, and peripherals including the left fusiform gyrus, MTG, and PFC, also showed significant neural synchrony. Other regions that showed significant neural synchrony were the right thalamus, left crus I, bilateral crus II, bilateral precentral gyrus, left TPJ, and bilateral frontal poles.

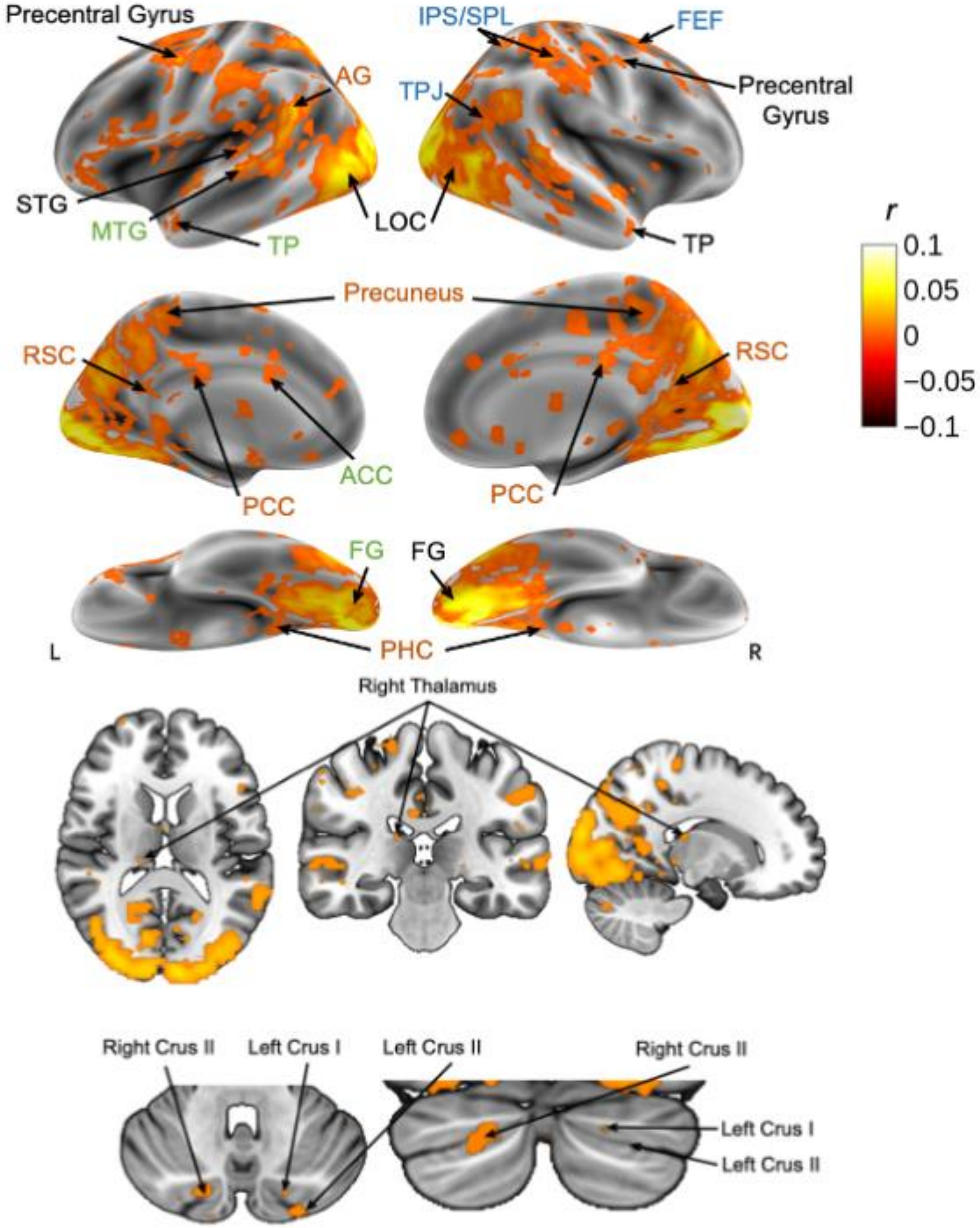


Figure 2.7. *500 Days of Summer*: Set-up > Resolution Synchrony. Synchrony maps derived from fMRI data during audiovisual movie watching. Maps are shown for the left (L) and right (R) hemispheres, in the lateral, medial, and inferior orientations. Areas in blue represent neural correlates of visuospatial attention, areas in green represent neural correlates of semantic memory, and areas in orange represent neural correlates of episodic memory.

Table 2.6. *500 Days of Summer:* Set-up > Resolution Cluster Table. Coordinates in MNI space. Only clusters with five or more voxels are reported.

Anatomical Location	**# of Voxels**	**Max *t***	**Max x**	**Max y**	**Max z**
Occipital Pole	3832	0.108	10.5	-91.5	1.5
Lateral Occipital Cortex, superior divison	143	0.0523	-22.5	-76.5	52.5
Superior Parietal Lobule	81	0.0284	34.5	-40.5	61.5
Angular Gyrus	69	0.0417	-58.5	-55.5	19.5
Angular Gyrus	67	0.05	58.5	-49.5	22.5
Precuneous Cortex	49	0.0339	-13.5	-52.5	40.5
Precentral Gyrus	45	0.043	-52.5	-4.5	52.5
Middle Frontal Gyrus	43	0.0209	31.5	-1.5	64.5
Postcentral Gyrus	39	0.0247	-61.5	-22.5	40.5
Precentral Gyrus	38	0.0224	-31.5	-7.5	61.5
Superior Temporal Gyrus, posterior divison	33	0.0409	64.5	-31.5	1.5
Planum Polare	33	0.044	49.5	4.5	-4.5
Inferior Frontal Gyrus	29	0.0254	-52.5	22.5	-4.5
Lateral Occipital Cortex, superior divison	25	0.0262	49.5	-64.5	46.5
Superior Temporal Gyrus, posterior divison	20	0.0407	-55.5	-37.5	4.5
Precuneous Cortex	17	0.0267	1.5	-49.5	64.5
Precentral Gyrus	16	0.0193	16.5	-31.5	64.5
Lateral Occipital Cortex, superior divison	15	0.0317	34.5	-58.5	58.5
Heschl's Gyrus	15	0.0359	-49.5	-10.5	1.5
Precentral Gyrus	14	0.0162	-37.5	-16.5	43.5
Cingulate Gyrus, posterior division	12	0.0169	-7.5	-43.5	1.5
Juxtapositional Lobule Cortex	12	0.0144	-4.5	4.5	70.5
Right Crus I	11	0.0153	22.5	-79.5	-34.5
Superior Temporal Gyrus, posterior divison	11	0.051	-67.5	-25.5	1.5
Postcentral Gyrus	10	0.0224	-13.5	-46.5	55.5
Superior Parietal Lobule	10	0.0171	-19.5	-52.5	70.5
Precuneous Cortex	9	0.0182	13.5	-40.5	52.5
Supramarginal Gyrus, anterior division	9	0.0211	-58.5	-34.5	55.5
Left Crus II	9	0.0217	-25.5	-88.5	-34.5
Precentral Gyrus	9	0.0171	40.5	-13.5	46.5
Temporal Pole	9	0.0232	-52.5	19.5	-22.5
Precentral Gyrus	8	0.0264	55.5	-1.5	49.5
Supramarginal Gyrus, anterior division	8	0.0283	52.5	-34.5	58.5
Temporal Pole	7	0.0218	-52.5	4.5	-22.5
Temporal Pole	6	0.0185	52.5	7.5	-22.5
Central Opercular Cortex	6	0.0127	-55.5	-22.5	19.5
Temporal Fusiform Cortex, posterior division	6	0.0127	-34.5	-34.5	-22.5
Cuneal Cortex	6	0.0318	-7.5	-82.5	40.5
Precentral Gyrus	5	0.018	-55.5	4.5	37.5
Right Crus II	5	0.0129	28.5	-85.5	-37.5
Superior Parietal Lobule	5	0.0156	19.5	-49.5	70.5
Frontal Pole	5	0.0177	-49.5	37.5	-10.5
Middle Temporal Gyrus, posterior division	5	0.0131	61.5	-22.5	-10.5

Note. Coordinates are in MNI space. Clusters with extent less than five voxels are not reported.

Resolution > Set-up. Results from the one-way LME for the Resolution > Set-up contrast identified 14 significant clusters of neural synchrony (see Figure 2.8 and Table 2.7). The left ACC, a hub implicated in semantic memory, showed significant neural synchrony. Other regions that showed significant neural synchrony were the right frontal pole, precentral gyrus, and left insular cortex. We did not find significant neural synchrony in visuospatial attention or episodic memory areas.

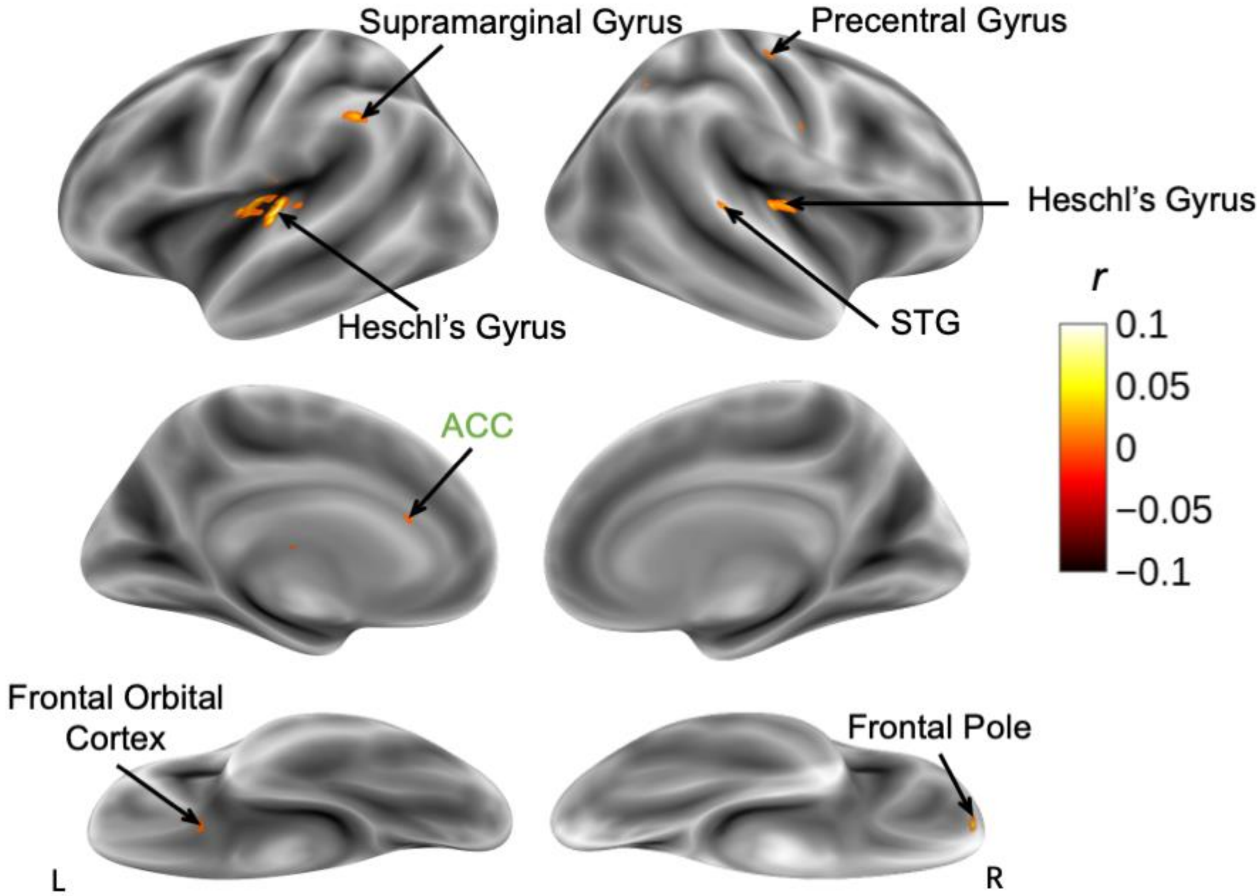
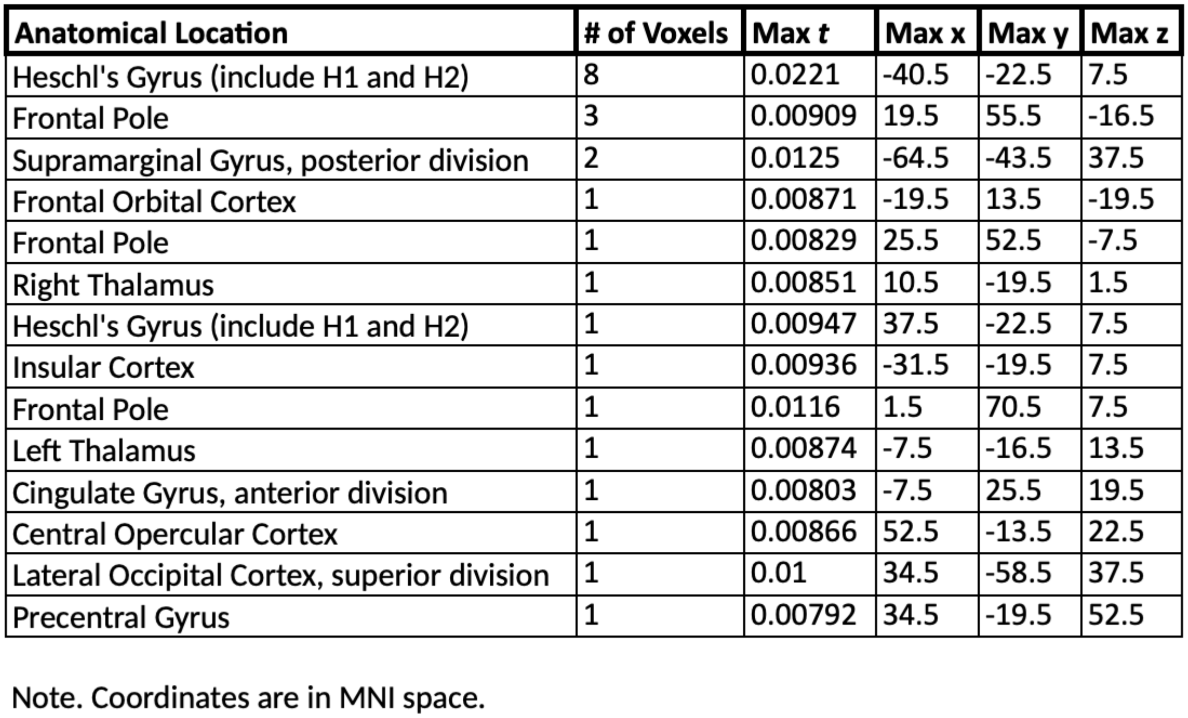


Figure 2.8. *500 Days of Summer*: Resolution > Set-up Synchrony. Synchrony maps derived from fMRI data during audiovisual movie watching. Maps are shown for the left (L) and right (R) hemispheres, in the lateral, medial, and inferior orientations. Areas in green represent neural correlates of semantic memory.

Table 2.7. *500 Days of Summer:* Resolution > Set-up Cluster Table. Coordinates in MNI space.



Anatomical Location	**# of Voxels**	**Max *t***	**Max x**	**Max y**	**Max z**
Heschl's Gyrus (include H1 and H2)	8	0.0221	-40.5	-22.5	7.5
Frontal Pole	3	0.00909	19.5	55.5	-16.5
Supramarginal Gyrus, posterior division	2	0.0125	-64.5	-43.5	37.5
Frontal Orbital Cortex	1	0.00871	-19.5	13.5	-19.5
Frontal Pole	1	0.00829	25.5	52.5	-7.5
Right Thalamus	1	0.00851	10.5	-19.5	1.5
Heschl's Gyrus (include H1 and H2)	1	0.00947	37.5	-22.5	7.5
Insular Cortex	1	0.00936	-31.5	-19.5	7.5
Frontal Pole	1	0.0116	1.5	70.5	7.5
Left Thalamus	1	0.00874	-7.5	-16.5	13.5
Cingulate Gyrus, anterior division	1	0.00803	-7.5	25.5	19.5
Central Opercular Cortex	1	0.00866	52.5	-13.5	22.5
Lateral Occipital Cortex, superior division	1	0.01	34.5	-58.5	37.5
Precentral Gyrus	1	0.00792	34.5	-19.5	52.5

Note. Coordinates are in MNI space.

Development vs. Resolution

Development > Resolution. Results from the one-way LME for the Development > Resolution contrast found 34 significant clusters of neural synchrony (see Figure 2.9 and Table 2.8). Significant clusters in visuospatial attention areas included the right FEF, SPL, TPJ, and IFG/MFG. Significant clusters in episodic memory areas included the left mPFC, bilateral precuneus, PHC, RSC, AG, and PCC. Semantic memory areas, including the hubs of the left temporal pole, and peripherals including the left fusiform gyrus, MTG, and PFC, also showed significant neural synchrony. Other regions that showed significant neural synchrony were the bilateral crus I and left crus II of the cerebellum, the bilateral precentral gyrus, the frontal pole, and left TPJ.

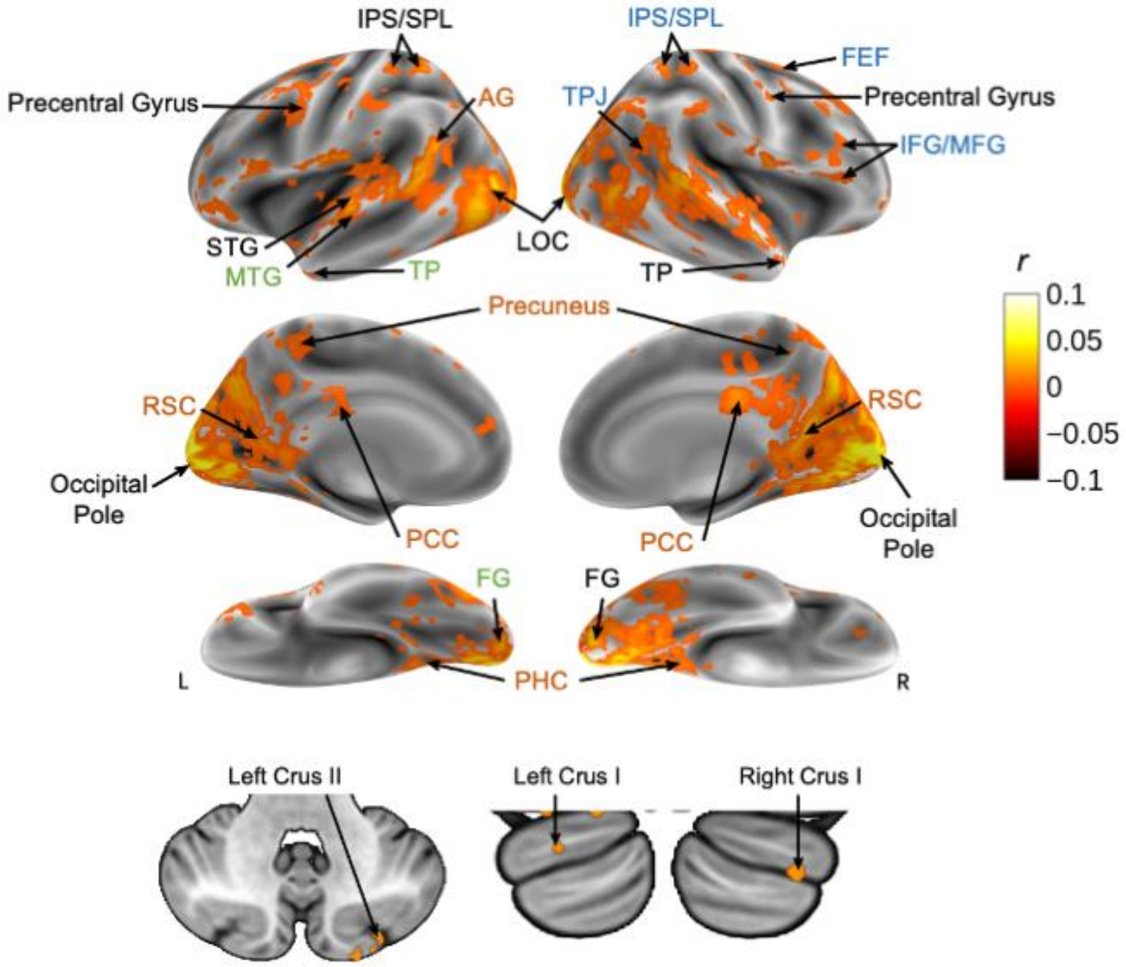
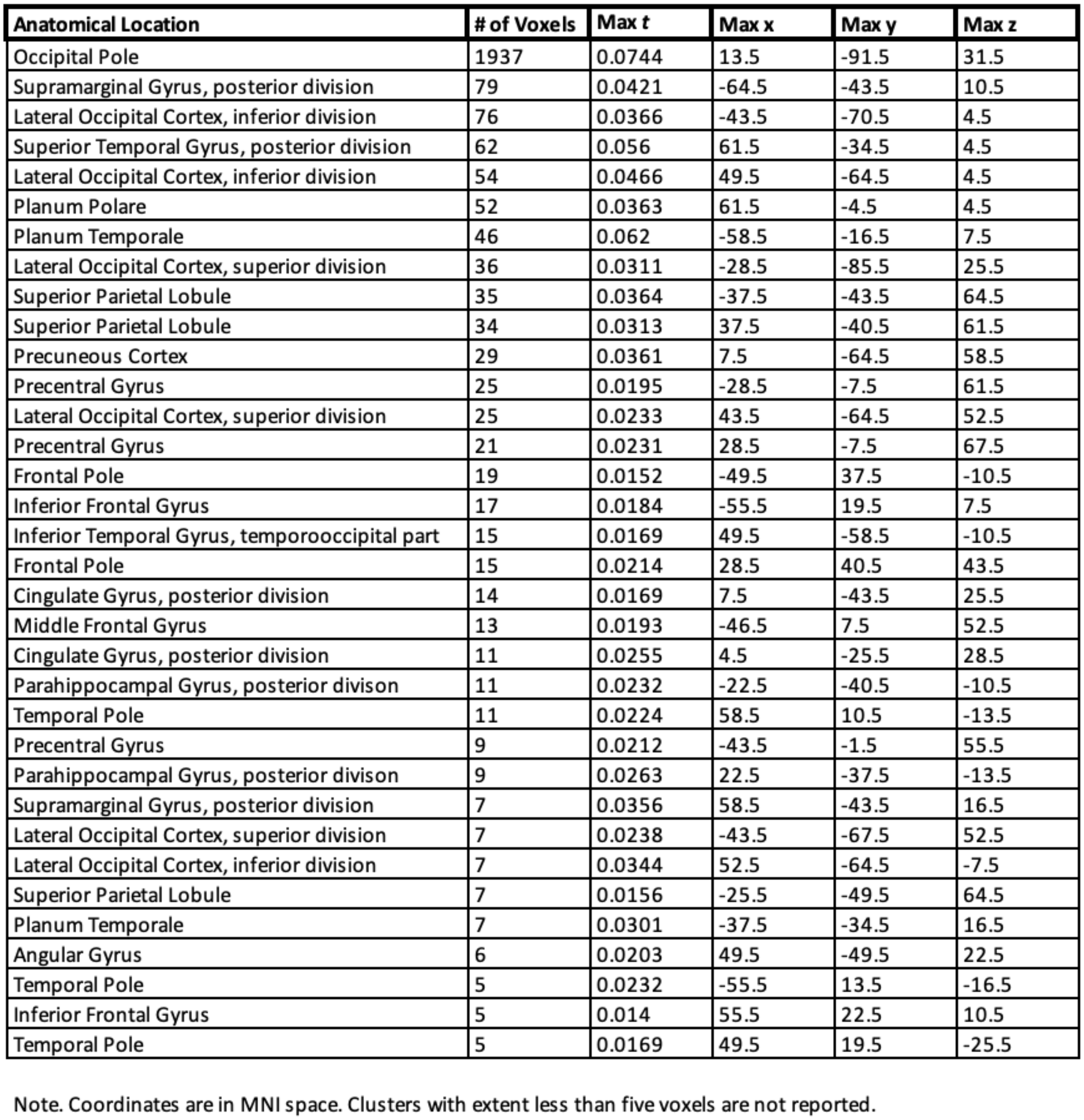


Figure 2.9. *500 Days of Summer:* Development > Resolution Synchrony. Synchrony maps derived from fMRI data during audiovisual movie watching. Maps are shown for the left (L) and right (R) hemispheres, in the lateral, medial, and inferior orientations. Areas in blue represent neural correlates of visuospatial attention, areas in green represent neural correlates of semantic memory, and areas in orange represent neural correlates of episodic memory.

Table 2.8. *500 Days of Summer:* Development > Resolution Cluster Table. Coordinates in MNI space. Only clusters with five or more voxels are reported.



Anatomical Location	**# of Voxels**	**Max *t***	**Max x**	**Max y**	**Max z**
Occipital Pole	1937	0.0744	13.5	-91.5	31.5
Supramarginal Gyrus, posterior division	79	0.0421	-64.5	-43.5	10.5
Lateral Occipital Cortex, inferior division	76	0.0366	-43.5	-70.5	4.5
Superior Temporal Gyrus, posterior division	62	0.056	61.5	-34.5	4.5
Lateral Occipital Cortex, inferior division	54	0.0466	49.5	-64.5	4.5
Planum Polare	52	0.0363	61.5	-4.5	4.5
Planum Temporale	46	0.062	-58.5	-16.5	7.5
Lateral Occipital Cortex, superior division	36	0.0311	-28.5	-85.5	25.5
Superior Parietal Lobule	35	0.0364	-37.5	-43.5	64.5
Superior Parietal Lobule	34	0.0313	37.5	-40.5	61.5
Precuneous Cortex	29	0.0361	7.5	-64.5	58.5
Precentral Gyrus	25	0.0195	-28.5	-7.5	61.5
Lateral Occipital Cortex, superior division	25	0.0233	43.5	-64.5	52.5
Precentral Gyrus	21	0.0231	28.5	-7.5	67.5
Frontal Pole	19	0.0152	-49.5	37.5	-10.5
Inferior Frontal Gyrus	17	0.0184	-55.5	19.5	7.5
Inferior Temporal Gyrus, temporooccipital part	15	0.0169	49.5	-58.5	-10.5
Frontal Pole	15	0.0214	28.5	40.5	43.5
Cingulate Gyrus, posterior division	14	0.0169	7.5	-43.5	25.5
Middle Frontal Gyrus	13	0.0193	-46.5	7.5	52.5
Cingulate Gyrus, posterior division	11	0.0255	4.5	-25.5	28.5
Parahippocampal Gyrus, posterior divison	11	0.0232	-22.5	-40.5	-10.5
Temporal Pole	11	0.0224	58.5	10.5	-13.5
Precentral Gyrus	9	0.0212	-43.5	-1.5	55.5
Parahippocampal Gyrus, posterior divison	9	0.0263	22.5	-37.5	-13.5
Supramarginal Gyrus, posterior division	7	0.0356	58.5	-43.5	16.5
Lateral Occipital Cortex, superior division	7	0.0238	-43.5	-67.5	52.5
Lateral Occipital Cortex, inferior division	7	0.0344	52.5	-64.5	-7.5
Superior Parietal Lobule	7	0.0156	-25.5	-49.5	64.5
Planum Temporale	7	0.0301	-37.5	-34.5	16.5
Angular Gyrus	6	0.0203	49.5	-49.5	22.5
Temporal Pole	5	0.0232	-55.5	13.5	-16.5
Inferior Frontal Gyrus	5	0.014	55.5	22.5	10.5
Temporal Pole	5	0.0169	49.5	19.5	-25.5

Note. Coordinates are in MNI space. Clusters with extent less than five voxels are not reported.

Resolution > Development. Results from the one-way LME for the Resolution > Development contrast did not find any regions with significant synchrony in visuospatial attention, semantic memory, and episodic memory areas. Other regions that showed significant neural synchrony were the right insular cortex, right temporal pole, and inferior temporal gyrus.

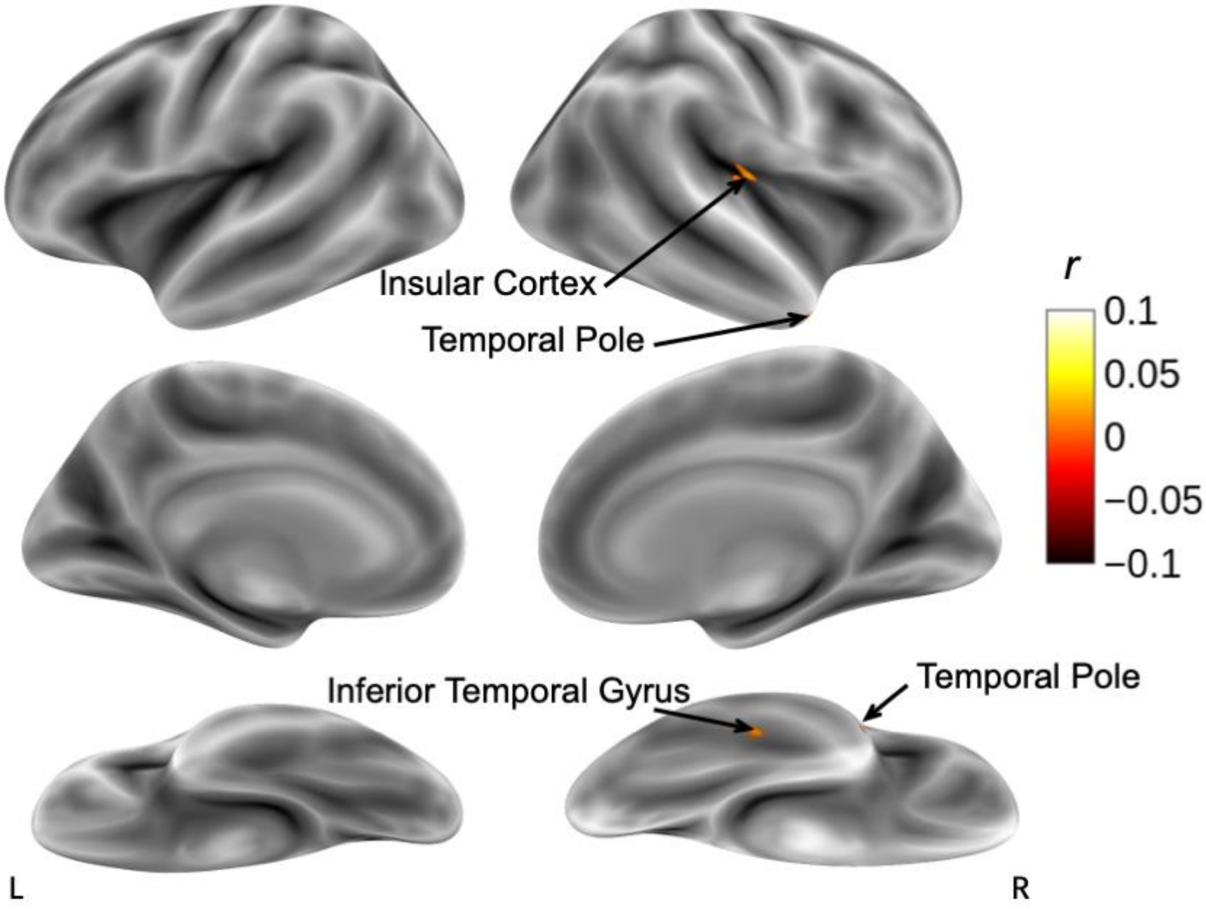


Figure 2.10. *500 Days of Summer:* Resolution > Development Synchrony. Synchrony maps derived from fMRI data during audiovisual movie watching. Maps are shown for the left (L) and right (R) hemispheres, in the lateral, medial, and inferior orientations.

Table 2.9. *500 Days of Summer:* Resolution > Development Cluster Table. Coordinates in MNI space.

Anatomical Location	**# of Voxels**	**Max *t***	**Max x**	**Max y**	**Max z**
Temporal Pole	1	0.00946	49.5	16.5	-37.5
Inferior Temporal Gyrus, posterior division	1	0.00833	46.5	-28.5	-25.5
Right I-IV	1	0.00956	7.5	-49.5	-19.5
Insular Cortex	1	0.00971	34.5	-22.5	16.5
Left Cerebral White Matter	1	0.00856	-19.5	-55.5	37.5

3.4 Discussion

Set-up

The Set-up phase involves establishing the storyline, introducing characters and their connections, and integrating this information. During the Set-up section, the right SPL (responsible for goal-directed attention), and left precuneus and AG (linked to episodic memory) showed greater neural synchrony compared to the Development section. Additionally, greater synchrony was observed in the left fusiform gyrus and IPS, known to play roles in semantic memory. These tasks demand significant engagement from attentional systems to create a cohesive representation of the provided information. Further, both semantic and episodic memory-related areas displayed greater neural synchrony during the Set-up phase compared to the Development phase, including the left precuneus and AG (episodic memory regions), and the left fusiform gyrus and IPS (semantic memory areas). This suggests greater involvement of memory processes, both semantic and episodic, during the initial third of the narrative compared to the middle section. This heightened memory engagement aligns with the introduction of characters, their goals, morals, story settings, and relationships, all of which require substantial memory integration.

The contrast between the Set-up and Resolution phases of the narrative revealed significant patterns of neural synchrony. Specifically, areas associated with attention exhibit increased neural synchrony during the Set-up, particularly in regions linked to goal-directed attention, including the right FEF and SPL, as well as the right TPJ which is involved in stimulus-driven attention. Moreover, areas involved in episodic memory (bilateral mPFC, precuneus, PHC, RSC, AG, and PCC) and semantic memory (left temporal pole (hub), ACC (hub), and peripheral areas: the left fusiform gyrus, MTG, and PFC) also show greater neural synchrony during the Set-up phase than Resolution. Overall, these findings suggest that the areas responsible for directing attention toward essential stimuli for constructing a coherent narrative representation exhibit higher synchrony during the Set-up phase than during the Development and Resolution sections. Additionally, the engagement of semantic and episodic memory processes appears to be more prominent during the Set-up phase compared to the Resolution phase. This indicates the greater cognitive demands associated with these memory types during the initial stages of narrative construction.

Areas outside of the models that showed significant synchrony included the precentral gyrus (Set-up > Development, Set-up > Resolution), the right thalamus (Set-up > Resolution), the bilateral crus II (Set-up > Resolution) and the left crus I (Set-up > Resolution). The precentral gyrus is implicated in functional tasks such as discourse comprehension (Lin et al., 2018) as well as it is a part of the mirror neuron system which is implicated in social cognition (Jáni & Kašpárek, 2018). The right thalamus is suggested to be involved attention (Halassa & Kastner, 2017; Ursey & Henry, 2015), as well as visual processing in terms of transmitting visual information to the cortex (Ursey & Henry, 2015). Finally, research showed that social mentalizing is supported by the crus II (Overwalle et al., 2020). In the context of the Set-up, this would align with the cognitive demands of mentalizing associated with this narrative segment. Given that there is a considerable amount of mentalizing involved in comprehending and empathizing with characters in narratives and this concept extends to our interactions with individuals in our daily lives as well. Additionally, the synchrony observed in the lateral occipital cortices, occipital poles, and superior temporal gyri coincides with processing an audiovisual stimuli .

Development

In terms of Development, specific brain areas exhibited contrasting patterns of synchrony between the Development and Set-up sections. In the Development section, the right IFG/MFG, (linked to stimulus-driven attention) and left AG (involved in episodic memory processes) displayed greater synchrony. Further, we found higher neural synchrony in the Development section than in the Resolution section in attentional regions such as the right FEF, SPL, IFG/MFG, and TPJ. This synchrony encompasses both goal-driven and stimulus-driven attention, suggesting that within the Development section, there might be a transitional shift between goal-directed and stimulus-driven attention, highlighting the dynamic interplay between these two cognitive systems. There is also a heightened engagement of semantic memory regions (i.e., the left temporal pole, fusiform gyrus, MTG and PFC) during the Development phase compared to the Resolution, suggesting that as new semantic information is encountered and processed, it needs to be seamlessly integrated into the subject's evolving narrative understanding. This synchrony within semantic memory regions supports the encoding and retention of this influx of information. These findings offer insight into evolving cognitive processes during narrative comprehension. The observed shift in attentional mechanisms from goal-directed attention to more stimulus-driven attention points to a dynamic change in how the brain allocates focus and responds to different narrative elements as the story unfolds in Development. As well, the minimal differences between Set-up and Development suggests that they have similar cognitive demands.

Similar to Set-up, the precentral gyrus showed synchronous activity in this section of the narrative. As previously discussed, the precentral gyrus is involved in discourse comprehension (Lin et al., 2018) as well as it is a part of the mirror neuron system which is implicated in social cognition (Jáni & Kašpárek, 2018). Additionally, the synchrony observed in the lateral occipital cortices, occipital poles, and superior temporal gyri coincides with processing an audiovisual stimulus (Jääskeläinen et al., 2020).

Resolution

When contrasting the Resolution and Set-up phases, patterns of synchrony in the left ACC showed more synchrony during Resolution than Set-up. This region is considered to be a semantic memory hub. When assessing synchrony in semantic and episodic memory, besides the left ACC, there are no other areas within either of these networks that show greater synchrony during Resolution than Set-up or Development. This could suggest that there are significant differences in cognitive demands when comparing the initial stages of a narrative (Set-up and Development) and the end (Resolution), however, visuospatial attention, semantic memory, and episodic memory are less engaged during the final portion of the narrative. This decrease is reflected in the observed lower level of neural synchrony during the Resolution section when contrasted with the Set-up or Development sections.

Conclusion

In summary, this experiment offers valuable insight into the dynamic shifts in cognitive demands associated with narrative processing. While previous research has provided evidence of neural correlates connected to narrative processing (e.g., (Jääskeläinen et al., 2020; Kauttonen et al., 2018; Tylén et al., 2015) the precise timing of these neural correlates coming into play during the narrative has remained largely unexplored. Here, we examined differences in neural synchrony between the three stages of an evolving narrative. Overall, we found that as the narrative evolves, there are changes in the cognitive demands associated with visuospatial attention, semantic memory, and episodic memory. This finding is supported by the patterns of neural synchrony observed in each of the six contrasts. However, it is important to note that this experiment is focused exclusively on a single narrative following the three-act structure. Consequently, the generalizability of our findings to other narratives may be limited. Nevertheless, the methodology adopted in this study significantly advances our comprehension of the cognitive processes underpinning narrative processing, which lays the foundation for subsequent experiments.

Experiment 3

4.1 Introduction

Experiments 1 and 2 provided valuable insight into how neural synchrony changes across three acts of a single Hollywood film. However, a limitation of these experiments is the use of only one full-length feature film due to constraints imposed by ISC and LME. Specifically, to run LME models with ISC data the ISCs must be calculated for all unique subject pairings, which requires that each functional file consists of the same number of volumes. Thus, we were unable to disentangle areas specifically related to narrative processing in general from changes that are a result of the stimulus. It is possible that aspects of the stimulus itself, such as audiovisual stimulation or lack of engaging material, would result in synchrony across subjects independent of narrative processing. Therefore, Experiment 3 was designed to assess the findings of Experiment 1 across a broader scope of narratives by applying a 3-act narrative structure sampling approach across 10 feature-length films (i.e., 10 unique narratives). The primary aim of Experiment 3 was to extend the findings of Experiment 1 and draw more robust and widely applicable conclusions about the neural responses associated with the 3-act narrative structure. Our hypotheses for Experiment 3 are similar to Experiment 1, centred around the idea that the cognitive demands induced by the narrative would dynamically evolve as the story unfolds. We expected to observe diverse patterns in the neural processes engaged during the perception, comprehension, and engagement with the narrative across the three phases: Set-up, Development, and Resolution.

Set-up

Similar to Experiment 1, this contrast aimed to uncover neural synchrony in brain regions associated with visuospatial attention, semantic memory, and episodic memory in the Set-up portion of the films. We hypothesized that regions associated with attention, semantic memory, and episodic memory would exhibit significant synchrony as participants construct cohesive narrative representations during this section of the films. Additionally, the set-up section is characterized by a substantial influx of narrative information, which may result in significant synchrony in both semantic and episodic memory systems. Further, we hypothesized that there would be synchrony in the dorsal attentional system due to the goal-directed nature of attention in this segment.

Development

Parallel to Experiment 1, this contrast aimed to uncover neural synchrony in brain regions associated with visuospatial attention, semantic memory, and episodic memory in the Development portion of the films. We hypothesized that areas involved in episodic memory, semantic memory, and stimulus-driven attention would continue to show significant synchronous activity, whereas areas involved in goal-directed attention, namely the right FEF and IPS/SPL may not show significant synchrony. This hypothesis was made with consideration of the cognitive demands of the Development section. This segment is still characterized by a consistent influx of both semantic and episodic information, translating to synchronous activity in these regions. In terms of attention, this section would exhibit more synchronized activity driven by the stimulus and its sensory features, rather than being directed toward a specific task or objective.

Resolution

This contrast aimed to assess synchrony in brain regions involved in visuospatial attention, semantic memory, and episodic memory during the Resolution portion of the films. We hypothesized that regions associated with goal-directed attention, semantic memory, and episodic memory would exhibit diminished synchrony during the concluding phase of the narrative. Conversely, areas connected with stimulus-driven attention would exhibit significant neural synchrony. These hypotheses were formulated with consideration for the cognitive demands present within this narrative section, as well as bearing in mind the results from Experiments 1 and 2. This section is characterized by the Resolution of narrative elements and the culmination of the story's progression. New information is sparse, leading to a decreased demand for goal-directed attention. Consequently, sensory aspects of the film are anticipated to hold sway over attention. In terms of semantic and episodic memory, the scarcity of fresh plot-driven information could render these cognitive needs inconsequential in the narrative's final stages. Consequently, this could result in less neural synchrony within the corresponding neural regions.

4.2 Methods

The methods for Experiment 3 are the same as Experiment 1, with the following exceptions.

Participants

For this study, we used preprocessed fMRI data from the NNdB (Aliko et al., 2021) v2.0. This database consists of 86 functional datasets of participants that watched one of ten full-length feature films. For this experiment, we utilized functional datasets of sixty participants (29 female, average age = 26.6 years) who watched one of ten full-length feature films during fMRI. We used datasets from six participants from each of the 10 films to ensure that the synchrony reflected in our results was not driven by any specific narrative. All participants were right-handed, native English speakers, had unimpaired or corrected-to-normal vision, no hearing impairments, and had no history of neurological or psychiatric illnesses (see Aliko et al., 2021 for detailed information).

Materials and Stimuli

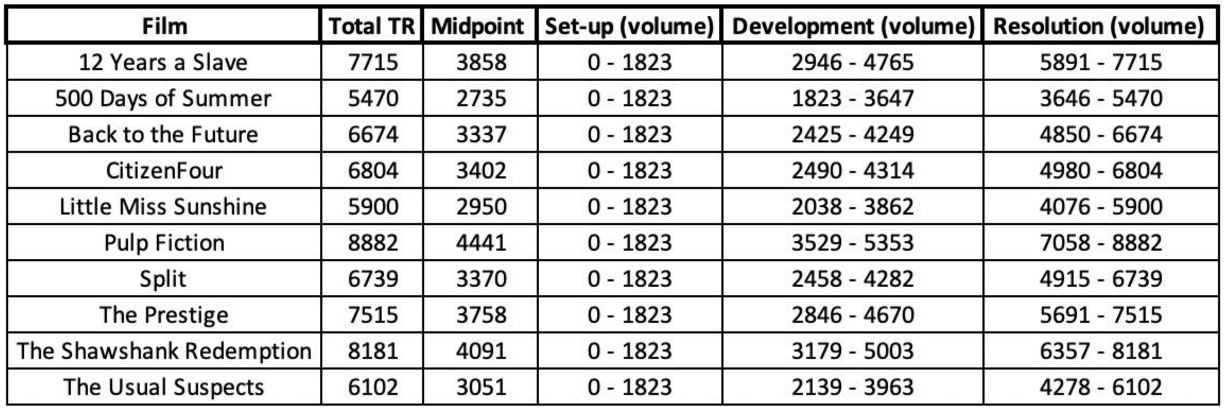
Participants watched one of ten full-length films included in the NNdB. These films spanned genres including romance, science fiction, documentary, comedy, and others. Participants underwent a screening process to assess if they had seen any of the films. Participants were randomly assigned to specific films, taking into consideration any prior exposure to the database movies.

Data Preprocessing

To perform ISC analysis across the ten different films, we selected an equal number of volumes for each section from each film, rather than splitting the number of fMRI volumes for each movie into equal thirds. We used *fslroi* (Jenkinson et al., 2012) to create distinct sections within each film, namely the Set-up, Development, and Resolution sections. Among the ten films analyzed, *500 Days of Summer* (Webb, 2009) had the fewest acquired volumes (5470). Consequently, each of the film sections (Set-up, Development, and Resolution) contained 1824 volumes, and this number of volumes was used across all 10 films as follows: the Set-up sections started at volume 1 and extended until volume 1823. The Development sections began 912 volumes before the middle volume and continued for an additional 912 volumes beyond the middle volume. The Resolution sections commenced 1824 volumes before the final volume and encompassed all the volumes until the last acquired volume. In cases where the midpoint volume of a film did not correspond to a whole number, it was rounded up to the nearest volume.

The exact divisions for each of the ten films can be found in Table 2.10.

Table 2.10. Sampled 3-Act Structure Film Divisions. Divisions of all films into Set-up, Development, and Resolution using a sampled 3-act structure.



Film	Total TR	Midpoint	Set-up (volume)	Development (volume)	Resolution (volume)
12 Years a Slave	7715	3858	0 - 1823	2946 - 4765	5891 - 7715
500 Days of Summer	5470	2735	0 - 1823	1823 - 3647	3646 - 5470
Back to the Future	6674	3337	0 - 1823	2425 - 4249	4850 - 6674
CitizenFour	6804	3402	0 - 1823	2490 - 4314	4980 - 6804
Little Miss Sunshine	5900	2950	0 - 1823	2038 - 3862	4076 - 5900
Pulp Fiction	8882	4441	0 - 1823	3529 - 5353	7058 - 8882
Split	6739	3370	0 - 1823	2458 - 4282	4915 - 6739
The Prestige	7515	3758	0 - 1823	2846 - 4670	5691 - 7515
The Shawshank Redemption	8181	4091	0 - 1823	3179 - 5003	6357 - 8181
The Usual Suspects	6102	3051	0 - 1823	2139 - 3963	4278 - 6102

Data Analysis

Using the new split functional files, ISC pairings were generated with AFNI's *3dTcorrelate* (Cox, 1996), resulting in 1770 unique ISC pairings (60 subjects across all movies) for each film section. In-house Python code was used to create the *3dISC* call (Chen et al., 2017; Cox, 1996) populating all the necessary files for conducting LME analysis on each section. The LME output file consisted of two volumes: (1) the overall *t*-stat image and (2) the ISC image for each contrast. This output file was divided using in-house Python code to provide the overall *t*-stat image and ISC image separate from one another. Once the overall *t*-stat image was obtained, AFNI was utilized to determine the critical *t*-stats for each of the film sections at $q < 0.0001$. The critical *t*-stats for the narrative Set-up, Development, and Resolution sections were 4.9815, 5.1099, and 5.2734, respectively. Critical *t*-stats were used to threshold the images using the *fslmaths* '-thr' function (Jenkinson et al., 2012) and masked onto the ISC image using the *fslmaths* '-mas' function.

4.3 Results

Set-up

Results from the one-way LME for the Set-up contrast found 11 significant clusters of neural synchrony across the brain (see Figure 2.11 and Table 2.11). In line with our hypotheses, we found significant neural synchrony in regions associated with visuospatial attention, including the right FEF, SPL, TPJ, and the IFG/MFG. Further, we found significant neural synchrony in regions associated with episodic memory, specifically in the bilateral precuneus, RSC, AG, and PCC and the right PHC. We also found significant neural synchrony in the semantic memory network, including the left temporal pole (hub), fusiform gyrus (peripheral), and posterior MTG (peripheral). In addition, we found significant neural synchrony in the bilateral precentral gyrus and the right postcentral gyrus.

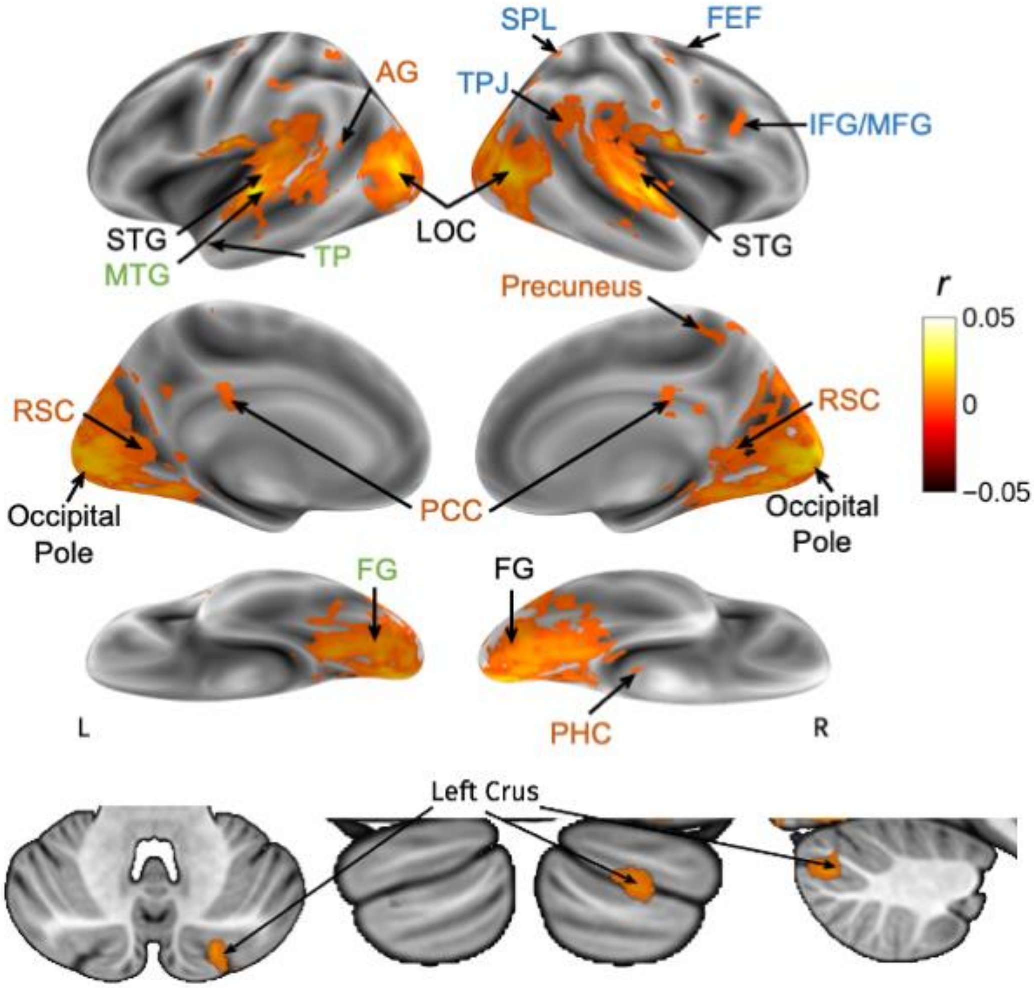
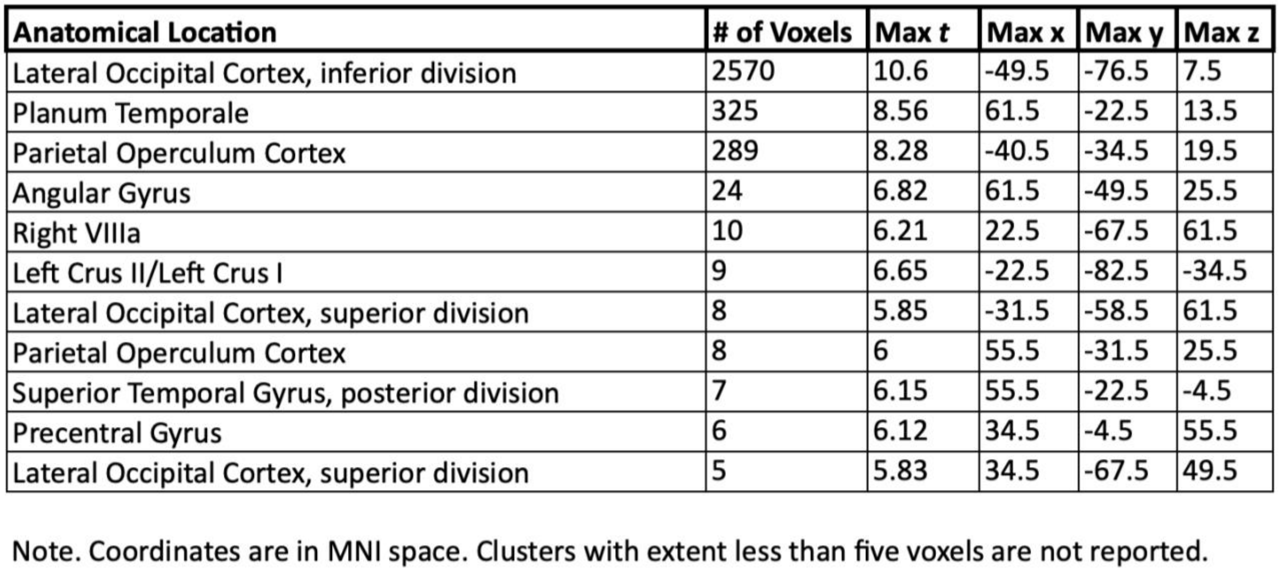


Figure 2.11. All movies*:* Set-up synchrony. Synchrony maps derived from fMRI data during audiovisual movie watching. Maps are shown for the left (L) and right (R) hemispheres, in the lateral, medial, and inferior orientations. Areas in blue represent neural correlates of visuospatial attention, areas in green represent neural correlates of semantic memory, and areas in orange represent neural correlates of episodic memory.

Table 2.11 All movies: Set-up Cluster Table. Coordinates in MNI space. Only clusters with five or more voxels are reported.



Anatomical Location	**# of Voxels**	**Max *t***	**Max x**	**Max y**	**Max z**
Lateral Occipital Cortex, inferior division	2570	10.6	-49.5	-76.5	7.5
Planum Temporale	325	8.56	61.5	-22.5	13.5
Parietal Operculum Cortex	289	8.28	-40.5	-34.5	19.5
Angular Gyrus	24	6.82	61.5	-49.5	25.5
Right VIIIa	10	6.21	22.5	-67.5	61.5
Left Crus II/Left Crus I	9	6.65	-22.5	-82.5	-34.5
Lateral Occipital Cortex, superior division	8	5.85	-31.5	-58.5	61.5
Parietal Operculum Cortex	8	6	55.5	-31.5	25.5
Superior Temporal Gyrus, posterior division	7	6.15	55.5	-22.5	-4.5
Precentral Gyrus	6	6.12	34.5	-4.5	55.5
Lateral Occipital Cortex, superior division	5	5.83	34.5	-67.5	49.5

Note. Coordinates are in MNI space. Clusters with extent less than five voxels are not reported.

Development

Results from the one-way LME for the Development contrast found 20 significant clusters of neural synchrony across the brain (see Figure 2.12 and Table 2.12). We found significant neural synchrony in regions associated with visuospatial attention, including the right SPL, TPJ, and IFG/MFG. Further, we found significant neural synchrony in regions associated with episodic memory, specifically in the bilateral precuneus, RSC, AG, PCC and right PHC. There was one region with significant neural synchrony in the semantic memory system, the left fusiform gyrus, the remaining semantic regions showed no significant neural synchrony during this narrative section. In addition, we found significant clusters of neural synchrony in areas such as the left precentral gyrus, IFG and right temporal pole.

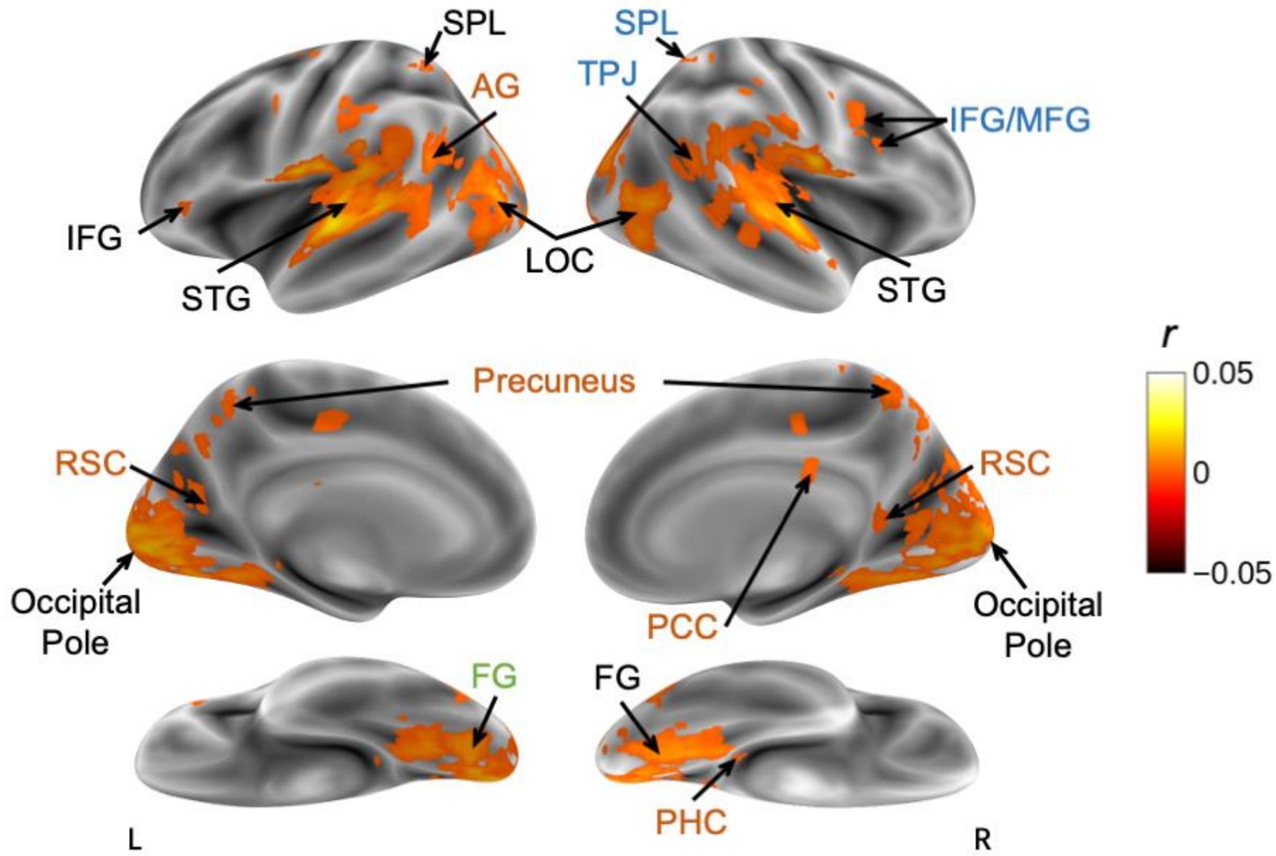
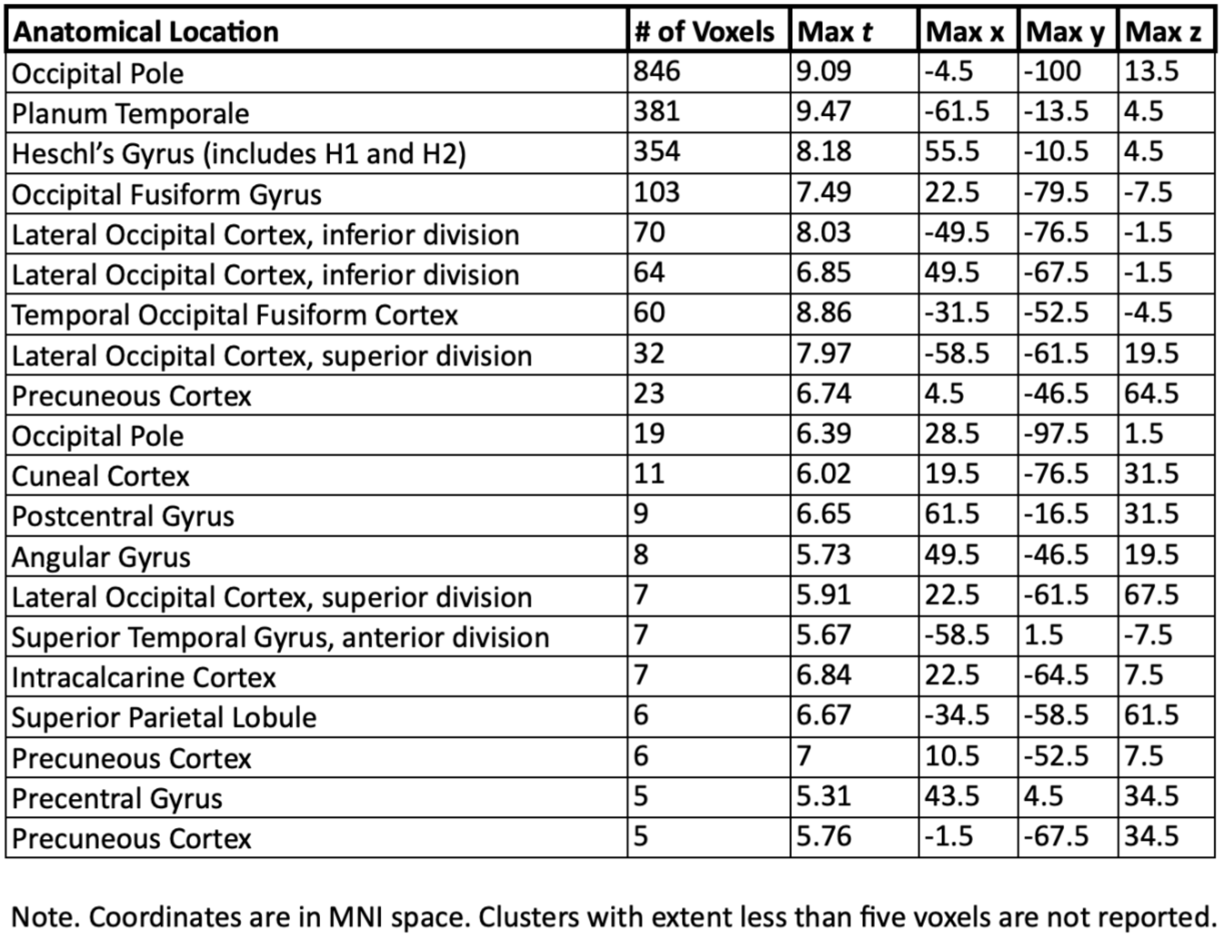


Figure 2.12. All movies: Development Synchrony. Synchrony maps derived from fMRI data during audiovisual movie watching. Maps are shown for the left (L) and right (R) hemispheres, in the lateral, medial, and inferior orientations. Areas in blue represent neural correlates of visuospatial attention, areas in green represent neural correlates of semantic memory, and areas in orange represent neural correlates of episodic memory.

Table 2.12. All movie: Development Cluster Table. Coordinates in MNI space. Only clusters with five or more voxels are reported.



Anatomical Location	**# of Voxels**	**Max *t***	**Max x**	**Max y**	**Max z**
Occipital Pole	846	9.09	-4.5	-100	13.5
Planum Temporale	381	9.47	-61.5	-13.5	4.5
Heschl's Gyrus (includes H1 and H2)	354	8.18	55.5	-10.5	4.5
Occipital Fusiform Gyrus	103	7.49	22.5	-79.5	-7.5
Lateral Occipital Cortex, inferior division	70	8.03	-49.5	-76.5	-1.5
Lateral Occipital Cortex, inferior division	64	6.85	49.5	-67.5	-1.5
Temporal Occipital Fusiform Cortex	60	8.86	-31.5	-52.5	-4.5
Lateral Occipital Cortex, superior division	32	7.97	-58.5	-61.5	19.5
Precuneous Cortex	23	6.74	4.5	-46.5	64.5
Occipital Pole	19	6.39	28.5	-97.5	1.5
Cuneal Cortex	11	6.02	19.5	-76.5	31.5
Postcentral Gyrus	9	6.65	61.5	-16.5	31.5
Angular Gyrus	8	5.73	49.5	-46.5	19.5
Lateral Occipital Cortex, superior division	7	5.91	22.5	-61.5	67.5
Superior Temporal Gyrus, anterior division	7	5.67	-58.5	1.5	-7.5
Intracalcarine Cortex	7	6.84	22.5	-64.5	7.5
Superior Parietal Lobule	6	6.67	-34.5	-58.5	61.5
Precuneous Cortex	6	7	10.5	-52.5	7.5
Precentral Gyrus	5	5.31	43.5	4.5	34.5
Precuneous Cortex	5	5.76	-1.5	-67.5	34.5

Note. Coordinates are in MNI space. Clusters with extent less than five voxels are not reported.

Resolution

Results from the one-way LME for the Resolution contrast found 13 significant clusters of neural synchrony across the brain (see Figure 2.13 and Table 2.13). We found significant neural synchrony in regions associated with episodic memory, including the right precuneus and RSC and a region associated with semantic memory, the left fusiform gyrus. However, no significant synchrony was seen in visuospatial attention regions.

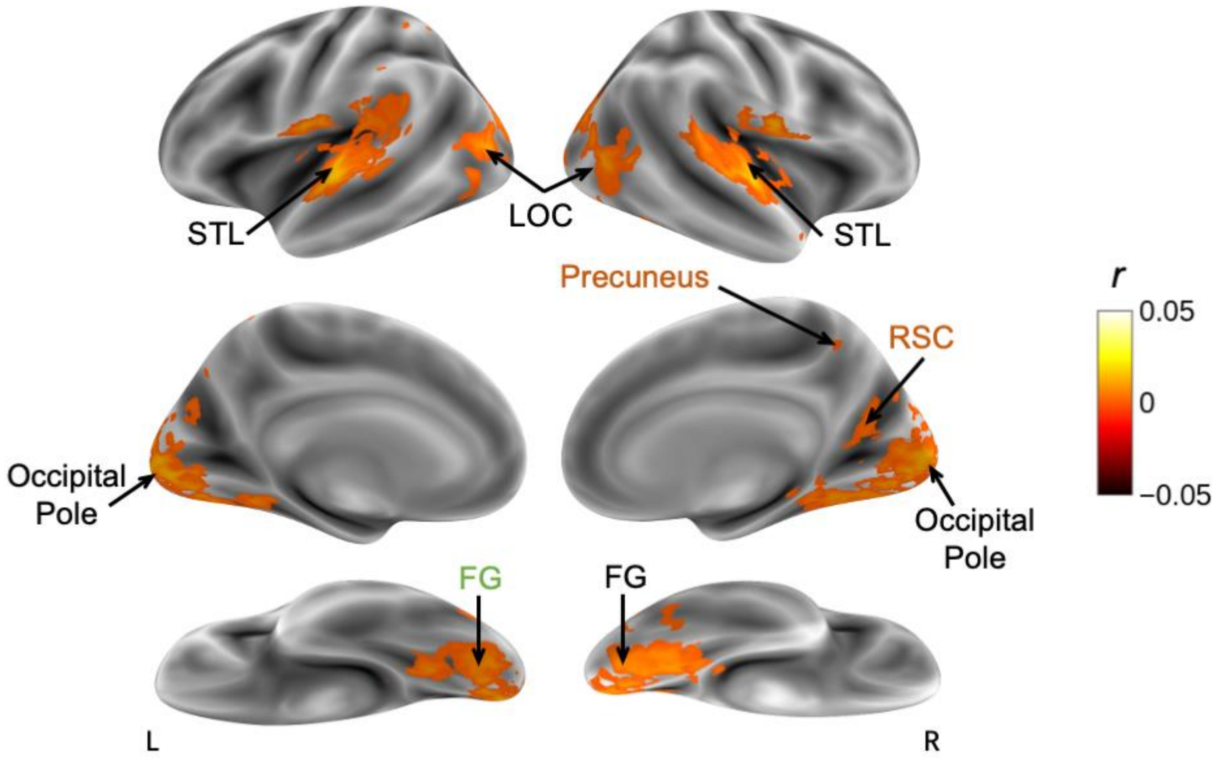
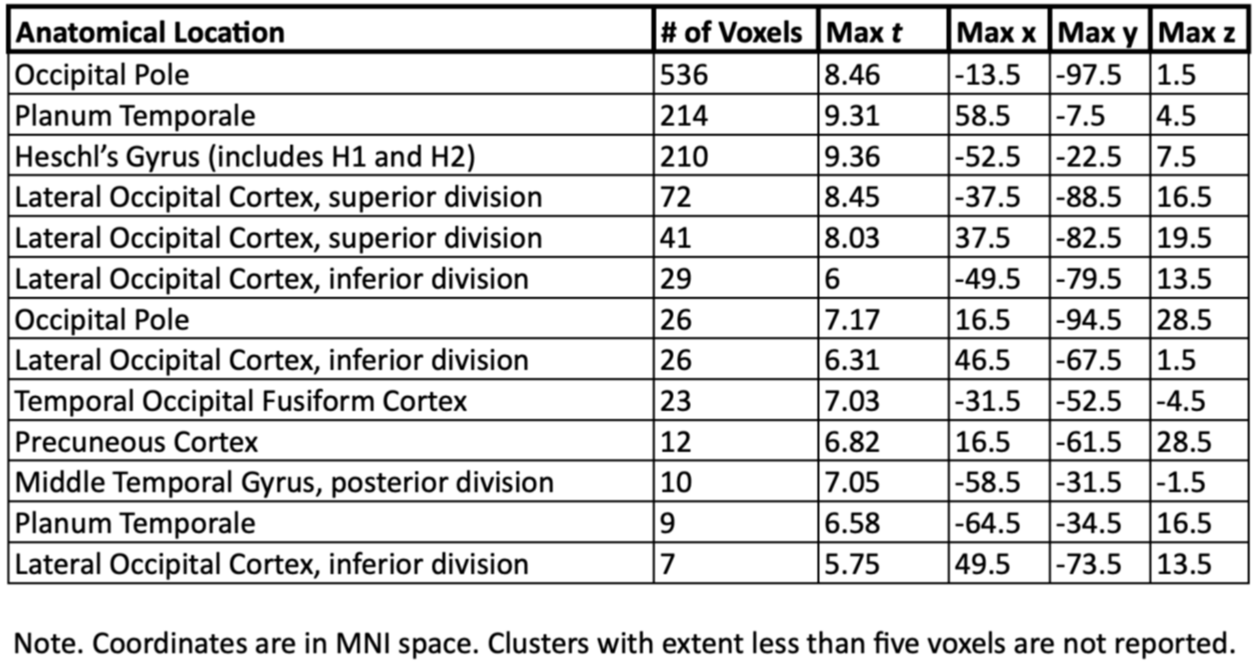


Figure 2.13. All movies: Resolution Synchrony. Synchrony maps derived from fMRI data during audiovisual movie watching. Maps are shown for the left (L) and right (R) hemispheres, in the lateral, medial, and inferior orientations. Areas in green represent neural correlates of semantic memory and areas in orange represent neural correlates of episodic memory.

Table 2.13. All movies: Resolution synchrony. Coordinates in MNI space. Only clusters with five or more voxels are reported.



Anatomical Location	# of Voxels	Max *t*	Max x	Max y	Max z
Occipital Pole	536	8.46	-13.5	-97.5	1.5
Planum Temporale	214	9.31	58.5	-7.5	4.5
Heschl's Gyrus (includes H1 and H2)	210	9.36	-52.5	-22.5	7.5
Lateral Occipital Cortex, superior division	72	8.45	-37.5	-88.5	16.5
Lateral Occipital Cortex, superior division	41	8.03	37.5	-82.5	19.5
Lateral Occipital Cortex, inferior division	29	6	-49.5	-79.5	13.5
Occipital Pole	26	7.17	16.5	-94.5	28.5
Lateral Occipital Cortex, inferior division	26	6.31	46.5	-67.5	1.5
Temporal Occipital Fusiform Cortex	23	7.03	-31.5	-52.5	-4.5
Precuneous Cortex	12	6.82	16.5	-61.5	28.5
Middle Temporal Gyrus, posterior division	10	7.05	-58.5	-31.5	-1.5
Planum Temporale	9	6.58	-64.5	-34.5	16.5
Lateral Occipital Cortex, inferior division	7	5.75	49.5	-73.5	13.5

Note. Coordinates are in MNI space. Clusters with extent less than five voxels are not reported.

4.4 Discussion

Set-up

Results from this experiment provide evidence for changing cognitive demands in attentional, semantic memory, and episodic memory systems over the course of the Set-up, Development, and Resolution phases of ten different audiovisual narratives. In line with Experiments 1 and 2, results from the Set-up portion of the film revealed significant clusters of neural synchrony in brain regions implicated in attentional processes, including the right FEF, SPL, TPJ, and IFG/MFG. The right FEF and SPL contribute to goal-directed attention (Corbetta & Shulman, 2002), suggesting there may be intentional allocation of attention to specific aspects of the story that are crucial for understanding plot development or character motivations. Additionally, the right TPJ and IFG/MFG play a role in stimulus-driven attention (Corbetta & Shulman, 2002). This suggests that certain events or stimuli in the narrative section may automatically capture the attention of the characters or the audience. The presence of both attentional systems suggests a coordinated interplay of these regions in guiding attentional processes for efficient focus on relevant stimuli during a section of the narrative characterized by the large influx of plot-relevant information. Synchronous activity in semantic memory areas, such as the left temporal pole, fusiform gyrus and MTG, suggests that the Set-up of the narrative introduces key conceptual information, themes, or facts that contribute to the overall understanding of the story's broader context. The audience gains essential knowledge about the world, characters, or plot developments, leading to a more comprehensive and meaningful narrative experience.

Similar to Experiment 1, we found significant synchrony in the left temporal pole, fusiform gyrus, and MTG. However, unlike Experiment 1, we did not find significant synchrony in the left ACC, left IPS, and PFC in this experiment. Synchronous engagement in episodic memory-associated regions (precuneus, RSC, AG, PCC, PHC) implies the involvement of these neural areas in processing and retaining the narrative's sequential events and contextual information. Compared to Experiment 1, fewer significant synchrony areas in the Set-up phase may suggest that aspects of the stimulus were driving synchrony in Experiment 1. In the Set-up phase, we found synchronous clusters in attention-related areas (right FEF, SPL, TPJ, IFG/MFG), signifying attention shifts from goal-directed to stimulus-driven. The identification of synchrony in semantic memory areas (left temporal pole, fusiform gyrus, MTG) in this section, suggests the introduction of key information required for the narrative framework.

Development

Results from the narrative Development section offer insights into the neural correlates of visuospatial attention, semantic memory, and episodic memory processes during this phase of the story. We found synchronous activity in the right SPL, involved in goal-directed attention, indicating that participants were intentionally directing their attention toward essential elements and plot points (Corbetta & Shulman, 2002). The right IFG/MFG and TPJ, associated with stimulus-driven attention, also exhibited synchronous activity. This indicates that certain aspects of the narrative captured attention automatically. Engagement of the left temporal pole (a semantic memory hub) during the narrative Development phase provides insight into how the brain processed conceptual information (Herlin et al., 2021). Synchronous activity in this area, as well as the left fusiform gyrus, is in line with the continued introduction of conceptual knowledge and thematic elements in this stage of the narratives. This might include details about the narrative’s setting, character backgrounds, or overarching themes that are crucial for understanding the narrative's deeper meaning and allow for the participant to create cohesive narrative representations. Neural synchrony in brain regions associated with episodic memory (i.e., the precuneus, RSC, AG, right PCC and PHC) suggests that the characters and audience were recalling or reflecting on past story events. These memories may have shaped the character's motivations, decisions, and emotional responses, providing continuity and depth to the unfolding narrative.

Resolution

Finally, during the Resolution section of the films, the left fusiform gyrus is the only semantic memory area with significant synchrony. This may suggest that during this phase the cognitive demands of exploring and processing details of the story, characters, and themes are reduced. As the story approaches its conclusion, the cognitive emphasis might shift from processing new information to reflecting on the broader implications and emotional impact of the unfolding events. This would explain the synchronous activity seen in areas with functions of episodic memory, including the right precuneus and RSC, as the cognitive demands shift to evoke emotional responses and engage the audience or characters.

Conclusion

In summary, the findings of Experiment 3 shed light on dynamic cognitive processes underlying narrative comprehension. Through the interplay of attentional, semantic memory, and episodic memory systems, neural synchrony infers intentional and automatic allocation of attention to essential narrative elements. During Set-up, regions with significant synchrony included the right FEF, SPL, TPJ, IFG/MFG (visuospatial attention), bilateral precuneus, RSC, AG, PCC, right PHC (episodic memory), left temporal pole, MTG, and fusiform gyrus (semantic memory). Development showed synchronous activity in the right SPL, TPJ, IFG/MFG (visuospatial attention), the bilateral precuneus, RSC, AG, right PCC, PHC (episodic memory), and the left fusiform gyrus (semantic memory). Finally, during Resolution the right precuneus, RSC (episodic memory), and left fusiform gyrus (semantic memory) were found to be synchronous. An important finding of Experiment 3 is that the synchrony observed in these results is independent of the narrative. With these findings, patterns of neural synchrony independent of stimuli begin to emerge and show the changes in cognitive demands, specifically visuospatial attention, episodic memory, and semantic memory, as the narrative progresses. This exploration of neural synchrony patterns deepens our understanding of how the human brain processes and interacts with unfolding narratives in this time frame, offering valuable insights into the cognitive mechanisms that underlie the integration of multimodal information over extended timescales.

Experiment 4

5.1 Introduction

Experiment 4 sought to examine differences between the three narrative stages (in a similar way to Experiment 2) using data from the same 10 films used in Experiment 3. To do so, we used the same pairwise ISC images as Experiment 3 to calculate differences between the three acts, resulting in six contrasts of interest: Set-up > Development, Development > Set-up, Set-up > Resolution, Resolution > Set-up, Development > Resolution, and Resolution > Development. Our hypotheses for Experiment 4 are similar to Experiment 2, centred around the idea that regions involved in goal-directed attention would be more synchronous during the initial stages of the narrative. Additionally, areas involved in semantic memory would reflect more synchronous activity during Set-up than Development, while areas involved in episodic memory would be more synchronous during Development than Set-up. Specific hypotheses are as follows:

Set-up vs. Development

We hypothesized that regions involved in goal-directed attention would be more synchronous during the initial stages of the narrative (i.e., Set-up) than Development. Additionally, areas involved in semantic memory would show greater synchrony during Set-up than Development, while areas involved in episodic memory would be more synchronous during Development than Set-up.

Set-up vs. Resolution

We hypothesized that regions involved in goal-directed attention would be more synchronous during the initial stages of the narrative, and regions involved in stimulus-directed attention would be more synchronous during the Resolution phase. Additionally, areas involved in semantic memory would reflect more synchronous activity during Set-up than Resolution, while areas involved in episodic memory would be more synchronous during Resolution than Set-up.

Development vs. Resolution

We hypothesized that regions involved in goal-directed attention would be more synchronous during the Development section of the narrative, and regions involved in stimulus-directed attention would be more synchronous during the Resolution phase. Additionally, areas involved in semantic memory would reflect more synchronous activity during Development than Resolution, while areas involved in episodic memory would be more synchronous during Resolution than Development.

5.2 Methods

Experiment 4 used the same participants, materials, stimuli, data acquisition, and data preprocessing procedures as Experiment 3, with the following exceptions.

Data Analysis

The same ISC pairings from Experiment 3 were used for this experiment. To assess differences in neural synchrony between the sampled film sections, we subtracted ISC pairings in the same way as Experiment 2. For the Set-up vs. Development contrast, each of the 1770 pairings from the Set-up section and its pair from the Development section was subtracted using *fslmaths* '-sub' (Jenkinson et al., 2012), and this process followed suit for the Set-up vs. Resolution contrast and Development vs. Resolution contrast. These files were used in the LME analysis for each contrast. Following LME analysis, the output file volumes were separated using in-house Python code to provide a *t*-stat and ISC image for each of the contrasts. Using AFNI (Cox, 1996), the *t*-stat images were used to generate critical *t* values for each of the contrasts at a *q* = 0.05. For Set-up vs. Development the critical *t* value was 5.2648, Set-up vs. Resolution was 4.7725, and Development vs. Resolution was 4.8993.

5.3 Results

Set-up vs. Development

Set-up > Development. We found 2 clusters of significant synchrony for the Set-up > Development contrast. These clusters were found in the bilateral occipital fusiform gyrus, as seen in Figure 2.14 and Table 2.14.

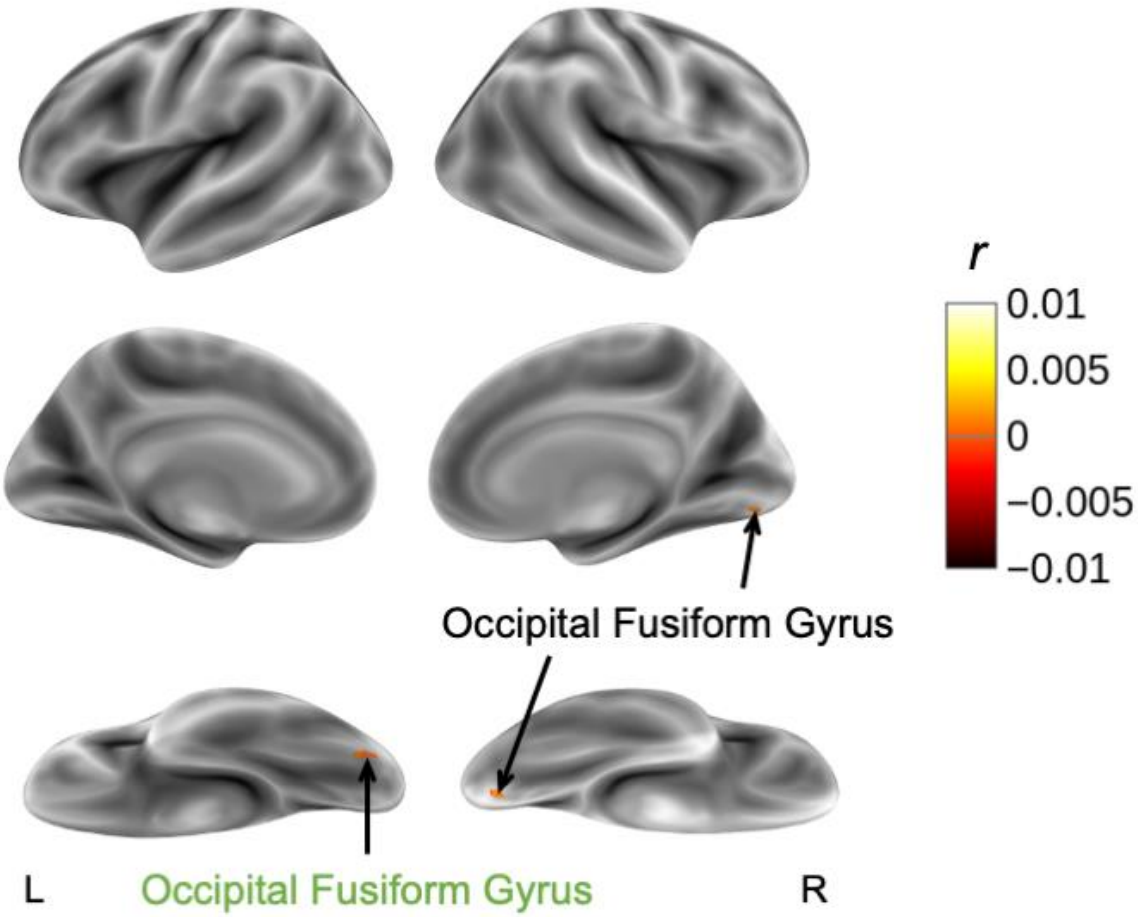
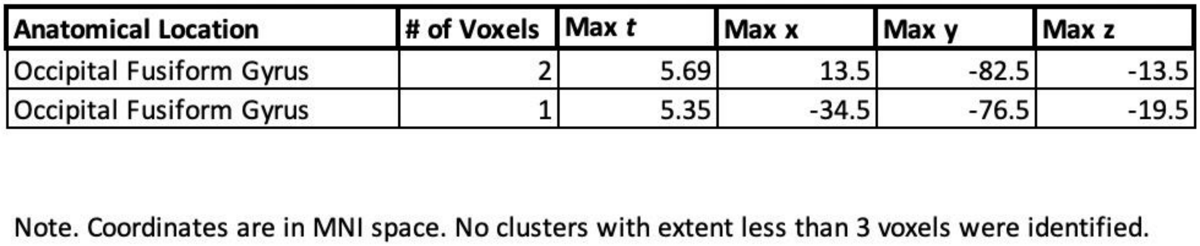


Figure 2.14. All movies: Set-up > Development Synchrony. Voxel-wise intersubject correlation revealing areas of neural synchrony for Set-up > Development contrast during audiovisual film

viewing. Correlation significance is reflected by color and scale is provided on the right, *r*. Maps are shown for the left (L) and right (R) hemispheres, in the lateral, medial, and inferior orientations.

Table 2.14. All movies: Set-up > Development Cluster Table. Coordinates in MNI space.



Anatomical Location	**# of Voxels**	**Max *t***	**Max x**	**Max y**	**Max z**
Occipital Fusiform Gyrus	2	5.69	13.5	-82.5	-13.5
Occipital Fusiform Gyrus	1	5.35	-34.5	-76.5	-19.5

Note. Coordinates are in MNI space. No clusters with extent less than 3 voxels were identified.

Set-up vs. Resolution

Set-up > Resolution. We found 7 clusters of significant neural synchrony for the Set-up > Resolution contrast. Areas with neural synchrony were the right visual (specifically the occipital pole), right intracalcarine cortex, and left planum temporale (i.e., auditory cortex), as seen in Figure 2.15 and Table 2.15.

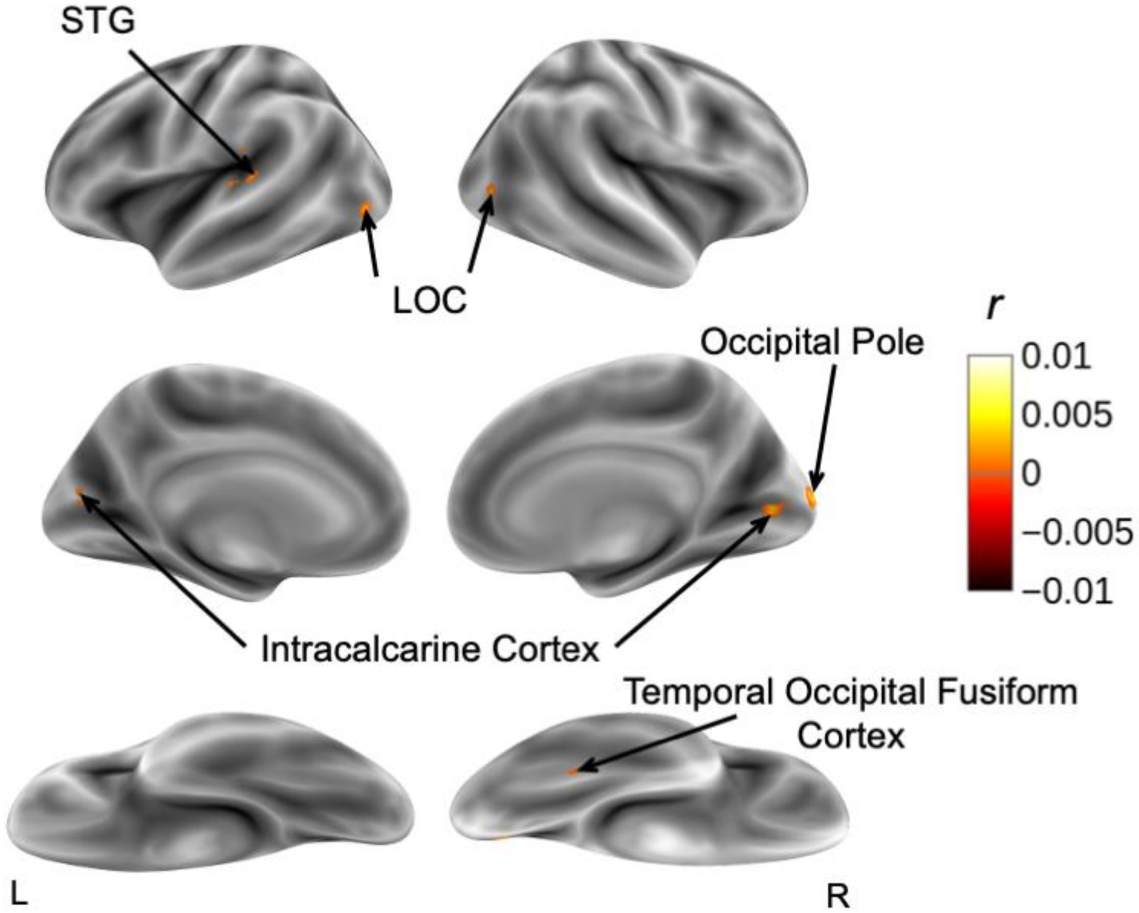


Figure 2.15. All movies: Set-up > Resolution Synchrony. Voxel-wise intersubject correlation revealing areas of neural synchrony for Set-up > Resolution contrast during audiovisual film viewing. Correlation significance is reflected by color and scale is provided on the right, *r*. Maps are shown for the left (L) and right (R) hemispheres, in the lateral, medial, and inferior orientations.

Table 2.15. All movies: Set-up > Resolution Cluster Table. Coordinates in MNI space.

Anatomical Location	**# of Voxels**	**Max *t***	**Max x**	**Max y**	**Max z**
Occipital Pole	11	5.82	13.5	-97.5	13.5
Intracalcarine Cortex	2	5.2	13.5	-76.5	7.5
Planum Temporale	2	5.1	-49.5	-31.5	7.5
Temporal Occipital Fusiform Cortex	1	4.81	34.5	-43.5	-19.5
Lateral Occipital Cortex, inferior division	1	5.14	-43.5	-73.5	-1.5
Lateral Occipital Cortex, inferior division	1	4.92	46.5	-73.5	4.5
Intracalcarine Cortex	1	5.44	-7.5	-70.5	13.5

Note. Coordinates are in MNI space. Clusters with extent less than five voxels are not reported.

The following contrasts did not identify any significant areas of synchrony: Development > Set-up, Resolution > Set-up, Development > Resolution, and Resolution > Development.

5.4 Discussion

Set-up vs. Development

The contrast comparing Set-up > Development across all 10 films showed neural synchrony in the right lingual gyrus and bilateral occipital fusiform gyrus. The lingual gyrus is involved in facial and visual processing, visual memory, and emotion (Palejwala et al., 2021). In terms of narrative processing, neural synchrony in this region across the 10 different narratives may suggest heightened engagement of facial and visual processing areas as the visual environment and characters are being learned and explored. In terms of episodic memory and attention, the regions associated with these cognitive processes as outlined in the model discussed in the introduction, did not show any significant synchronous activity in this contrast. This result indicates that these cognitive processes and their neural correlates are not reflecting variability in their degrees of synchrony between these narrative sections. Furthermore, this could be a result of the differences in narrative structure across all 10 films.

Set-up vs. Resolution

The contrast of Set-up > Resolution found significant neural synchrony in the left planum temporale, the right occipital pole, bilateral lateral occipital cortex, and the bilateral intracalcarine cortices. These areas play significant roles in visual and auditory processes. The planum temporale is implicated in language processes (Shapleske et al., 1999). Alongside the planum temporale, synchrony is observed in the lateral occipital cortices, intracalcarine cortices, and the right occipital pole. Jääskeläinen et al. (2020) found increased synchrony in these areas during engaging and arousing narrative presentations. This collective evidence implies that participants are more engaged during the Set-up section compared to the Resolution section. We did not find significant neural synchrony in any other semantic memory, episodic memory, or attentional areas. This suggests that the degrees of synchrony in these cognitive processes and their neural correlates do not significantly differ between these narrative sections.

No significant neural synchrony was observed for the following contrasts: Development > Set-up, Resolution > Set-up, Development > Resolution, and Resolution > Development. One potential explanation for this could be our lack of control over the 3-act structure present in each narrative. Some films might not have followed the traditional 3-act structure, which in turn might have caused an insufficient representation of their Set-up, Development, and Resolution phases. This could have led to an incomplete understanding of the cognitive demands within these specific parts of the narratives. Additionally, to optimize the utilization of ISC pairings and ensure compatibility with the ISC covariance structure, it was crucial that all Set-up, Development, and Resolution sections contained the same volume count. Unfortunately, adhering to this requirement resulted in the removal of volumes from nine out of ten movies. This limitation might have further contributed to the absence of significant results in these comparisons, potentially due to the loss of crucial narrative information.

Conclusion

In conclusion, the analysis of neural synchrony contrasted among different narrative sections within 10 films provides insights into cognitive engagement during distinct phases of narrative processing. The Set-up > Development contrast revealed heightened activity in regions linked to visual processing, implying engagement with visual aspects of the narrative. Moreover, the Set-up > Resolution comparison demonstrated significant synchrony in areas associated with auditory and visual processing. However, the absence of synchronous activity in contrasts involving Development and Resolution highlights the complexity of narrative structures across films and potential limitations in accurately capturing cognitive demands. Variations in narrative structure among the films could contribute to these observations. The restraints requiring the same number of volumes, while essential for analysis, might have led to data loss, possibly impacting the absence of significant results. These findings collectively underscore the intricate interplay between cognitive processes, neural activity, and narrative comprehension.

CHAPTER 3: GENERAL DISCUSSION

This thesis sought to identify the neural correlates of narrative processing in the human brain to elucidate how the communication and coordination between brain regions varied as information was integrated into long-term memory. To do so, we examined how neural synchrony changed over the course of complex audiovisual narratives in four experiments. We were specifically interested in how neural synchrony in visuospatial attentional brain regions (i.e., the right FEF, IPS/SPL, IFG/MFG, and TPJ), semantic memory regions (i.e., left temporal pole, ACC, fusiform gyrus, IPS, MTG, PFC), and episodic memory regions (i.e., precuneus, PHC, RSC, AG, mPFC, and PCC) changed over the Set-up, Development, and Resolution sections according to the typical three-act structure of Hollywood films. Our ultimate goal was to provide insight into how narratives become integrated into long-term memory in the human brain using naturalistic stimuli, which better encapsulate the demands of everyday life. In Experiments 1 and 2, we assessed synchrony in neural correlates of visuospatial attention, semantic memory, and episodic memory within three film sections (Set-up, Development, and Resolution) and looked at differences in the degree of neural synchrony when contrasting between the different sections in a single narrative. In Experiments 3 and 4, we extended the findings of Experiments 1 and 2 to a diverse series of narratives by using 10 different films. Neural synchrony in visuospatial attention, semantic memory, and episodic regions was explored within each section of the narrative (Set-up, Development, and Resolution) and contrasted between each of the sections. Our main findings are highlighted below.

The Neural Correlates of Building a Narrative: Set-up

The Set-up phase introduces the main protagonist and sets up the basis of the narrative. Based on the results of Experiments 1, 2, and 3, visuospatial attention, semantic memory, and episodic memory areas that consistently showed significant synchrony in this section were the right IPS/SPL (involved in goal-directed attention), the left fusiform gyrus (involved in semantic memory), and the bilateral AG and precuneus (involved in episodic memory). Thus, we propose that these regions encompass the core "narrative building" network in the brain (see Figure 3.1). More broadly, in terms of long-term narrative formation in a real-world setting, this suggests that the initial stages of memory formation rely upon areas involved in voluntary visuospatial attention, episodic memory, and semantic memory, and the integration of this information into coherent narrative frameworks. This stage of narrative processing sets the trajectory for the construction of a coherent narrative representation that serves as a scaffolding for subsequent narrative information.

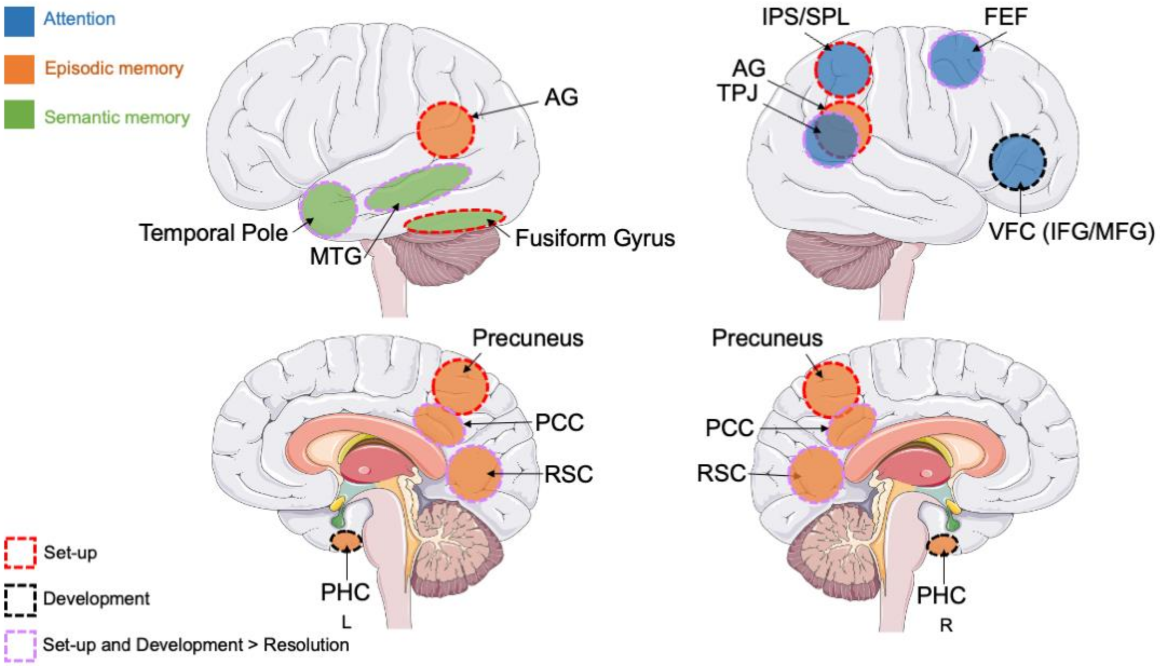


Figure 3.1. Core Neural Correlates of Narrative Integration: Set-up and Development Core Regions, and Set-up or Development > Resolution. Illustration of the neural correlates involved in narrative processing. The model proposes that red-outlined regions are associated with the Set-up phase, the black outline is implicated in the Development phase, and the purple-outlined

regions are implicated in Set-up or Development > Resolution. The model provides a comprehensive framework for understanding the neural correlates involved in processing narratives over extended timescales.

Previous literature highlights the importance of the SPL for updating neural representations. For example, Koenigs et al. (2009) found that damage to the SPL resulted in significant deficits on tests involving the manipulation and updating of working memory information. Thus, the SPL may play an important role in the construction and maintenance of narrative representations by continuously updating information in working memory in the early stages of the narrative. Our study underscores the significance of the SPL in the early phases of narrative processing. To establish cohesive narrative representations, it is crucial to meticulously and comprehensively update and support a narrative structure, a task to which the SPL significantly contributes. The AG, a region involved in episodic memory, is involved in multimodal sensory integration during both encoding and construction of coherent episodic memories (Tibon et al., 2019). These representations enable vivid recall during both encoding and retrieval (Ritchey & Cooper, 2020; Tibon et al., 2019). Furthermore, the precuneus is involved in updating mental story representations during narrative processing (Whitney et al., 2009) and narrative interpretation (Jääskeläinen et al., 2020). Our study, in addition to the above literature, implicates the AG and precuneus in episodic memory processes crucial to narrative processing. The AG allows for audiovisual sensory integration during the Set-up of the narrative, and in turn, allows for accurate and vivid recall of narrative-specific information. Additionally, the precuneus plays a crucial role in narrative interpretation, during the initial of the narrative, accurate interpretation is required to ensure coherent narrative representations.

The Neural Correlates of Developing a Narrative: Development

During the Development phase, the protagonist encounters progressively difficult obstacles as the narrative unfolds. As this section draws to a close, the protagonist confronts the most pivotal obstacle, intensifying tension and driving the narrative toward its climax. Based on the results of Experiments 1, 2, and 3, we identified a core narrative development network that includes the right IFG/MFG and the bilateral PHC. This is a particularly interesting finding, as it suggests that these areas may be involved in integrating information into long-term memory over longer timescales than the regions found in the Set-up portion. In contrast to set-up, involvement of the right IFG/MFG later in the narrative may be associated with a shift from voluntary attentional to reflexive, stimulus-driven attention (see Figure 3.1). Previous research examining narrative processing in individuals with unilateral brain injury found that damage to the IFG/MFG resulted in deficits in processing more complex narratives (Karaduman et al., 2017). As such, increased neural synchrony in this area during the development phase may reflect increased attentional demands to integrate the increasingly complex narrative over an extended timescale. Additionally, the PHC is implicated in memory system networks as a critical support of memory processes (Ward et al., 2014). Additionally, the PHC are critically affected in the manifestation of Alzheimer’s disease (Jacobs et al., 2012; Wang et al., 2012). These findings, in conjunction with our results, suggest the critical role of the PHC in the building and updating of information during long-term episodic memory processes within narrative processing.

We also found differences in cognitive demands between the beginning of narrative construction (either Set-up or Development) and Resolution. Areas involved in visuospatial attention, semantic memory, and episodic memory that showed greater synchrony in both Set-up or Development when compared to Resolution in Experiments 1-3 included the right FEF (goal-directed attention) and TPJ (stimulus-driven attention), semantic memory regions including the left temporal pole and MTG, and episodic memory regions including the bilateral RSC and PCC (see Figure 3.1). When considering memory formation in real-world contexts, these results infer that there are significant differences in the processing of narrative during the beginning versus the end of a complex narrative. This also means that a large part of how a narrative takes shape happens in the early stages, and therefore if there are issues during the early stages there is likely going to be difficulty creating coherent narrative representation. Based on our findings, these regions may play an important role in connecting different parts of a story and integrating them into a meaningful whole as the narrative progresses.

The Neural Correlates of Concluding a Narrative: Resolution

In the Resolution, the protagonist overcomes the most significant challenge, leading to the climactic moment and eventual resolution. We assessed this section both within a single film, as well as across 10 different films. In addition, we looked at this section compared to Set-up and Development, to assess any differences in the degrees of synchrony between this section and the other two. Based on the results of the experiments, there were no areas involved in visuospatial attention, semantic memory, and episodic memory that showed consistent synchrony in Experiments 1-3. Specifically, when looking at the Resolution > Set-up and Resolution > Development contrasts in Experiment 2, there was one semantic memory area (left ACC) that showed more synchrony in Resolution when compared to Set-up. This finding suggests that the cognitive demands of narrative processing during the initial stages (Set-up and Development) are significantly different than that of the ending (Resolution).

Together, the four experiments presented in this thesis provide evidence of evolving cognitive demands associated with the 3-act narrative structure results in dynamic changes in neural synchrony, specifically in terms of attention, semantic memory, and episodic memory. We identified two core narrative processing networks involved in building coherent representations over extended timescales. The neural correlates of these networks include the right FEF, IPS/SPL, TPJ, IFG/MFG (visuospatial attention), bilateral precuneus, PHC, AG, PCC, RSC (episodic memory), left temporal pole, MTG, and fusiform gyrus (semantic memory). We also identified several peripheral regions that appear to be more involved in processing earlier parts of the narrative (i.e., Set-up and Development) than the resolution. These include the right FEF and TPJ, left temporal pole and MTG, and bilateral RSC and PCC. Together, these regions form the scaffolding for successful narrative processing over the course of naturalistic stimuli. Experiment 1 and 2 results exhibit extensive sensory area synchronization in addition to narrative processing areas due to participants watching the same film. However, an advantage of Experiment 3 and 4 is the reduction in sensory driven synchronization by the use of 10 different films and the inclusion of both within and between moving ISC pairings in our LME analysis. This work offers valuable insight into narrative processing on extended timescales, mirroring processing that is more applicable to "real-world" scenarios and establishes a framework of neural correlates of long-term memory formation.

Current Study Findings and Previous Narrative Research

This thesis extends research focused on examining neural activity associated with naturalistic stimuli. Our novel approach of examining changes in neural synchrony associated with different stages of narrative processing (i.e., Set-up, Development, and Resolution) offers valuable insight into not only narrative processing as a whole, but also dynamic changes in cognitive demands. Previous research has generally employed brief naturalistic stimuli (Kauttonen et al., 2018; Tylén et al., 2015; Xu et al., 2005), limiting the ability to examine changing neural correlates over extended timescales. In contrast, the experiments in this thesis investigated a larger spectrum of narrative evolution, encompassing the unfolding cognitive engagement from inception to resolution within the three-act structure. For example, while Tylén et al. (2015) also found synchrony in the PCC, precuneus, temporal pole and TPJ in narrative processing during an audio narrative task, our results showed that these regions are particularly important during the initial stages of narrative processing and aid in the construction of coherent narrative frameworks that can later be built upon. In addition, Kauttonen and colleagues (2018) examined narrative processing in a manner similar to the current study. However, as previously mentioned, the present research sought to evaluate narrative processing more broadly, without focusing narrowly on specific components of narrative, such as the cued recall used in Kauttonen's study. Rather than examining the impact over the entire duration of a stimulus, a 105-minute film in the Kauttonen study, our goal was to evaluate the effects throughout the narrative's progression, with a focus on understanding the neural mechanisms associated with the narrative's Set-up, Development, and Resolution.

Our results also have important implications for understanding disorders marked by the breakdown of narrative processing, which may in turn help advance both clinical interventions and theoretical frameworks in the realm of cognitive neuroscience. In terms of dementia, a disease characterized by the breakdown of narrative, research suggests that, as the disease progresses, the ability to think of past personal experiences and one’s narrative self, declines (Mehl-Madrona & Mainguy, 2022). More specifically, research into semantic dementia, a disease marked by the loss of semantic memory in the context of preserved episodic memory, suggests that semantic knowledge is crucial for the construction of future novel events and provides an integral structure upon which episodic memory can be weaved to create coherent and cohesive representations (Irish et al., 2012). This research goes further to assess episodic future thinking in patients with semantic dementia contrasted to patients with Alzheimer’s disease, a neurodegenerative disease characterized by episodic memory dysfunction (Irish, 2023). In an attempt to evaluate their ability to imagine and describe future events, participants completed assessments designed to explore episodic and semantic thinking across past and future conditions, standardized tests of episodic and semantic memory, and MRI. Results of this study found that both groups showed significant impairments in episodic future thinking, the ability to imagine or simulate experiences that may occur in one’s personal future (Schacter et al., 2017). These impairments were correlated to atrophy in the left inferior temporal gyrus and bilateral temporal poles (semantic memory regions) and the posterior cingulate, parahippocampal gyrus and frontal pole (episodic memory regions; Irish et al., 2012).

In terms of narrative processing, episodic future thinking could be a significant cognitive mechanism in narrative processing, under the scope of episodic memory, as it is the process of an individual putting themselves in the shoes of characters within a narrative. In summary, the findings of the present study offer valuable insights into narrative processing over extended timescales, reflecting a form of long-term memory formation more aligned with real-world scenarios. Based on the literature discussed, our findings allow us to infer that memory loss associated with these different types of dementia and memory-related diseases would severely affect the ability to form coherent narrative representations. Areas like the temporal poles, PCC, and PHC are implicated in our results to play significant roles in the building and restructuring of narrative representations during the beginning stages of the narrative, as mentioned in the above literature. Therefore, translated into real-life scenarios, damage to these regions of the brain would result in detrimental effects on narrative processing.

Limitations and Future Directions

This study aimed at uncovering the neural underpinnings of narrative processing, however, there are several limitations to be discussed. Because we used data from an online database, we did not have control over the stimuli that were presented to the participants, limiting our control over plot content, length, and genre of the films chosen. While *500 Days of Summer* (Webb, 2009) adheres to the classic 3-act narrative structure (*How to Use the 500 Days of Summer Script to Master Non-Linear Storytelling*, 2011; Mesce, 2022) it is important to note that the remaining nine films in the NNdB extend across a wide range of genres and may not have plots that align perfectly with the 3-act structure. Thus, in Experiments 3 and 4, the split sections may not fully encapsulate the neural correlates associated with Set-up, Development, and Resolution in isolation. If the sections of the narrative overlapped and included parts from the Set-up, Development, or Resolution stages together, it could potentially lead to our results not showing meaningful differences between these sections. This may have contributed to the lack of significant differences in our regions of interest in Experiment 4. Future research should ensure that the films are broken down into 3-acts based on changes in the plot, which may provide a more accurate delineation of the neural correlates related to each act. However, because we were sampling from a 3-act narrative structure, we were still able to encompass the beginning, middle, and end of the narratives even if they were not following the 3-act structure perfectly. As discussed previously, the elimination of sensory driven synchrony can be seen as a limitation in the Experiment 1 and 2 results. Although Experiments 3 and 4 addressed some of these limitations, future research could consider employing an experimental design in which participants watch films sectioned into equal duration and with varying content. This approach would help mitigate sensory-driven synchronization. In addition, the data used in these experiments was collected using a 1.5T MRI, which has lower spatial specificity and a lower signal-to-noise ratio than stronger MRIs. The use of a higher Tesla scanner would better encapsulate finer details of functional activations. Future research should aim at using higher-resolution MRI instruments to acquire such data.

Moreover, ISC serves as an effective analysis tool for handling naturalistic data complexities. However, this led to the utilization of a sampled 3-act narrative structure for Experiments 3 and 4. As previously mentioned, ISC analysis involves correlating participants' data voxel-to-voxel over time courses of equal lengths. This poses a notable challenge when dealing with films that have a different number of volumes. Furthermore, to carry out LME (Chen et al., 2017; Cox, 1996) with ISC pairings, it is essential to have all distinct participant pairings available. Consequently, using an accurate one-third 3-act segmentation of the films, running ISC, and subsequently performing LME is not feasible because the correct count of ISC pairings would not be attainable. Future research could use tools like artificial intelligence to create novel films of different genres that follow the 3-act structure and have the same number of volumes per act.

Conclusion

In conclusion, this thesis explored narrative processing across three distinct phases of complex audiovisual narratives using naturalistic stimuli. Results from four experiments identified neural correlates associated with visuospatial attention, semantic memory, and episodic memory within the Set-up, Development, and Resolution segments of the narrative. The findings collectively emphasize dynamic changes in neural synchrony associated with evolving cognitive demands intrinsic to narrative structure. We found that the initial portion of narrative processing (Set-up) relies upon areas involved in visuospatial attention (right SPL), episodic memory (bilateral AG, precuneus), and semantic memory (left fusiform gyrus). Areas significantly involved in Development include the right IFG/MFG and the bilateral PHC. Additionally, we also found that the right FEF, TPJ (visuospatial attention), left temporal pole, MTG (semantic memory), and bilateral RSC and PCC (episodic memory) are significantly more synchronous during the beginning of a narrative (Set-up and Development) in comparison to the end (Resolution). This infers that these areas are involved in the formation of narrative representations that allow us to integrate information over extended timescales. In summary, the research presented in this thesis provides valuable insight into how knowledge is encoded, consolidated, and retrieved in the brain using naturalistic stimuli, shedding light on the fundamental mechanisms that shape cognition. This may inform strategies for enhancing memory-related interventions and treatments.

SUPPLEMENTARY MATERIAL

Appendix A: MRI Terminology

Volume	Refers to a three-dimensional (3D) representation of the brain or a portion of it, obtained through the acquisition of a stack of two-dimensional (2D) images or slices
Repetition Time (TR)	Parameter in magnetic resonance imaging (MRI) that specifies the time, in milliseconds (ms), between successive radiofrequency (RF) pulse sequences or data acquisitions; TR plays a critical role in determining the contrast and characteristics of MRI images
Echo Time (TE)	Refers to the time, typically measured in milliseconds (ms), between the application of a radiofrequency (RF) pulse and the peak of the resulting echo signal; plays a role in the image contrast, particularly in distinguishing between different tissue properties
Flip Angle	Represents the angle, usually measured in degrees, by which nuclear spins within the brain are rotated when they are excited by a radiofrequency (RF) pulse in an MRI scan
Resolution	Refers to the level of detail or clarity in the acquired image

REFERENCES

Aliko, S., Huang, J., Gheorghiu, F., Meliss, S., & Skipper, J. I. (2020). A naturalistic neuroimaging database for understanding the brain using ecological stimuli. *Scientific Data 2020 7:1*, *7*(1), 1–21. https://doi.org/10.1038/s41597-020-00680-2

Assouline, A., & Mendelsohn, A. (2019). Building a story: coherent narrative formation relies on functional connectivity in posterior cortex and frontoparietal networks. In *bioRxiv*. http://biorxiv.org/content/early/2019/06/12/667618.abstract

Benjamini, Y., & Hochberg, Y. (1995). Controlling the False Discovery Rate: A Practical and Powerful Approach to Multiple Testing. *Journal of the Royal Statistical Society: Series B (Methodological)*, *57*(1), 289–300. https://doi.org/10.1111/J.2517-6161.1995.TB02031.X

Binder, J. R., Desai, R. H., Graves, W. W., & Conant, L. L. (2009). Where is the semantic system? A critical review and meta-analysis of 120 functional neuroimaging studies. *Cerebral Cortex December*, *19*, 2767–2796. https://doi.org/10.1093/cercor/bhp055

Brütsch, M. (2015). The three-act structure: Myth or magical formula? *Journal of Screenwriting*, *6*(3), 301–326. https://doi.org/10.1386/josc.6.3.301_1

Cavanna, A. E., & Trimble, M. R. (2006). The precuneus: A review of its functional anatomy and behavioural correlates. *Brain*, *129*(3), 564–583. https://doi.org/10.1093/brain/awl004

Chen, G., Taylor, P. A., Shin, Y. W., Reynolds, R. C., & Cox, R. W. (2017). Untangling the relatedness among correlations, Part II: Inter-subject correlation group analysis through linear mixed-effects modeling. *NeuroImage*, *147*, 825–840. https://doi.org/10.1016/J.NEUROIMAGE.2016.08.029

Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience*, *3*(3), 201–215. https://doi.org/10.1038/nrn755

Cox, R. W. (1996). AFNI: software for analysis and visualization of functional magnetic resonance neuroimages. *Computers and Biomedical Research, an International Journal*, *29*(3), 162–173. https://doi.org/10.1006/cbmr.1996.0014

Cutting, J. E. (2016). Narrative theory and the dynamics of popular movies. *Psychonomic Bulletin and Review*, *23*(6), 1713–1743. https://doi.org/10.3758/S13423-016-1051-4/FIGURES/9

Cutting, J. E., Brunick, K. L., & Delong, J. E. (2011). How act structure sculpts shot lengths and shot transitions in Hollywood film. *Projections*, *5*(1), 1–16. https://doi.org/10.3167/proj.2011.050102

Davey, J., Thompson, H. E., Hallam, G., Karapanagiotidis, T., Murphy, C., De Caso, I., Krieger-Redwood, K., Bernhardt, B. C., Smallwood, J., & Jefferies, E. (2016). Exploring the role of the posterior middle temporal gyrus in semantic cognition: Integration of anterior temporal lobe with executive processes. *NeuroImage*, *137*, 165–177. https://doi.org/10.1016/j.neuroimage.2016.05.051

Deniz, F., Nunez-Elizalde, A. O., Huth, A. G., & Gallant, J. L. (2019). The representation of semantic information across human cerebral cortex during listening versus reading is invariant to stimulus modality. *Journal of Neuroscience*, *39*(39), 7722–7726. https://doi.org/10.1523/JNEUROSCI.0675-19.2019

Dickerson, B. C., & Eichenbaum, H. (2010). The episodic memory system: Neurocircuitry and disorders. *Neuropsychopharmacology*, *35*(1), 86–104. https://doi.org/10.1038/npp.2009.126

Ding, J., Chen, K., Liu, H., Huang, L., Chen, Y., Lv, Y., Yang, Q., Guo, Q., Han, Z., & Lambon Ralph, M. A. (2020). A unified neurocognitive model of semantics language social behaviour and face recognition in semantic dementia. *Nature Communications*, *11*(1), 1–14.

https://doi.org/10.1038/s41467-020-16089-9

Dugué, L., Merriam, E. P., Heeger, D. J., & Carrasco, M. (2018). Specific visual subregions of TPJ mediate reorienting of spatial attention. *Cerebral Cortex*, *28*(7), 2375–2390. https://doi.org/10.1093/cercor/bhx140

Gale, S. A., Acar, D., & Daffner, K. R. (2018). Dementia. *American Journal of Medicine*, *131*(10), 1161–1169. https://doi.org/10.1016/j.amjmed.2018.01.022

Guha, T., Kumar, N., Narayanan, S. S., & Smith, S. L. (2015). Computationally deconstructing movie narratives: An informatics approach. *ICASSP, IEEE International Conference on Acoustics, Speech and Signal Processing - Proceedings*, *2015-Augus*, 2264–2268. https://doi.org/10.1109/ICASSP.2015.7178374

Halassa, M. M., & Kastner, S. (2017). Thalamic functions in distributed cognitive control. *Nature Neuroscience*, *20*(12), 1669–1679. https://doi.org/10.1038/s41593-017-0020-1

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

Hasson, U., Nir, Y., Levy, I., Fuhrmann, G., & Malach, R. (2010). Intersubject synchronization of cortical activity during natural vision. *Advancement Of Science*, *252*(5664), 1634–1640.

Herlin, B., Navarro, V., & Dupont, S. (2021). The temporal pole: From anatomy to function—A literature appraisal. In *Journal of Chemical Neuroanatomy* (Vol. 113). Elsevier B.V. https://doi.org/10.1016/j.jchemneu.2021.101925

How to use the 500 Days of summer script to master non-linear storytelling. (2011). https://www.scriptreaderpro.com/500-days-of-summer-screenplay/

Irish, M. (2023). Autobiographical memory in dementia syndromes—An integrative review.

Wiley Interdisciplinary Reviews: Cognitive Science, *14*(3), 1–25. https://doi.org/10.1002/wcs.1630

Irish, M., Addis, D. R., Hodges, J. R., & Piguet, O. (2012). Considering the role of semantic memory in episodic future thinking: Evidence from semantic dementia. *Brain*, *135*(7), 2178–2191. https://doi.org/10.1093/brain/aws119

Jääskeläinen, I. P., Klucharev, V., Panidi, K., & Shestakova, A. N. (2020). Neural processing of narratives: From individual processing to viral propagation. *Frontiers in Human Neuroscience*, *14*(June), 1–9. https://doi.org/10.3389/fnhum.2020.00253

Jääskeläinen, I. P., Sams, M., Glerean, E., & Ahveninen, J. (2021). Movies and narratives as naturalistic stimuli in neuroimaging. *NeuroImage*, *224*. https://doi.org/10.1016/J.NEUROIMAGE.2020.117445

Jacobs, H. I. L., Van Boxtel, M. P. J., Jolles, J., Verhey, F. R. J., & Uylings, H. B. M. (2012). Parietal cortex matters in Alzheimer's disease: An overview of structural, functional and metabolic findings. *Neuroscience and Biobehavioral Reviews*, *36*(1), 297–309. https://doi.org/10.1016/j.neubiorev.2011.06.009

Jáni, M., & Kašpárek, T. (2018). Emotion recognition and theory of mind in schizophrenia: A meta-analysis of neuroimaging studies. In *World Journal of Biological Psychiatry* (Vol. 19, Issue sup3, pp. S86–S96). Taylor and Francis Ltd. https://doi.org/10.1080/15622975.2017.1324176

Jenkinson, M., Beckmann, C. F., Behrens, T. E. J., Woolrich, M. W., & Smith, S. M. (2012). FSL - Review. *NeuroImage*, *62*(2), 782–790. https://doi.org/10.1016/j.neuroimage.2011.09.015

Karaduman, A., Göksun, T., & Chatterjee, A. (2017). Narratives of focal brain injured individuals: A macro-level analysis. *Neuropsychologia*, *99*(October 2016), 314–325. https://doi.org/10.1016/j.neuropsychologia.2017.03.027

Kauttonen, J., Hlushchuk, Y., Jääskeläinen, I. P., & Tikka, P. (2018). Brain mechanisms underlying cue-based memorizing during free viewing of movie Memento. *NeuroImage*, *172*(December 2017), 313–325. https://doi.org/10.1016/j.neuroimage.2018.01.068

Koerner, T. K., & Zhang, Y. (2017). Application of linear mixed-effects models in human neuroscience research: A comparison with pearson correlation in two auditory electrophysiology studies. *Brain Sciences 2017, Vol. 7, Page 26*, *7*(3), 26. https://doi.org/10.3390/BRAINSCI7030026

León, C. (2016). An architecture of narrative memory. *Biologically Inspired Cognitive Architectures*, *16*, 19–33. https://doi.org/10.1016/j.bica.2016.04.002

Lin, N., Yang, X., Li, J., Wang, S., Hua, H., Ma, Y., & Li, X. (2018). Neural correlates of three cognitive processes involved in theory of mind and discourse comprehension. *Cognitive, Affective and Behavioral Neuroscience*, *18*(2), 273–283. https://doi.org/10.3758/s13415-018-0568-6

Martinez-Conde, S., Alexander, R. G., Blum, D., Britton, N., Lipska, B. K., Quirk, G. J., Swiss, J. I., Willems, R. M., & Macknik, S. L. (2019). The storytelling brain: How neuroscience stories help bridge the gap between research and society. *Journal of Neuroscience*, *39*(42), 8285–8290. https://doi.org/10.1523/JNEUROSCI.1180-19.2019

Meehan, T. P., Bressler, S. L., Tang, W., Astafiev, S. V., Sylvester, C. M., Shulman, G. L., & Corbetta, M. (2017). Top-down cortical interactions in visuospatial attention. *Brain Structure and Function*, *222*(7), 3127–3145. https://doi.org/10.1007/s00429-017-1390-6

Mehl-Madrona, L., & Mainguy, B. (2022). Neuroscience and narrative. *Anthropology of*

Consciousness, *33*(1), 79–95. https://doi.org/10.1111/anoc.12144

Mesce, B. (2022). *The myth of the three-act structure*.

Nastase, S. A., Gazzola, V., Hasson, U., & Keysers, C. (2019). Measuring shared responses across subjects using intersubject correlation. *Social Cognitive and Affective Neuroscience,* 669–687. https://doi.org/10.1093/scan/nsz037

Overwalle, F. Van, Ma, Q., & Heleven, E. (2020). The posterior crus II cerebellum is specialized for social mentalizing and emotional self-experiences: A meta-analysis. *Social Cognitive and Affective Neuroscience*, *15*(9), 905–928. https://doi.org/10.1093/scan/nsaa124

Palejwala, A. H., Dadario, N. B., Young, I. M., O'Connor, K., Briggs, R. G., Conner, A. K., O'Donoghue, D. L., & Sughrue, M. E. (2021). Anatomy and white matter connections of the lingual gyrus and cuneus. *World Neurosurgery*, *151*, e426–e437. https://doi.org/10.1016/j.wneu.2021.04.050

Ritchey, M., & Cooper, R. A. (2020). Deconstructing the Posterior Medial Episodic Network. *Trends in Cognitive Sciences*, *24*(6), 451–465. https://doi.org/10.1016/j.tics.2020.03.006

Schacter, D. L., Benoit, R. G., & Szpunar, K. K. (2017). Episodic future thinking: mechanisms and functions. *Current Opinion in Behavioral Sciences*, *17*, 41–50. https://doi.org/10.1016/j.cobeha.2017.06.002

Tibon, R., Fuhrmann, D., Levy, D. A., Simons, J. S., & Henson, R. N. (2019). Multimodal integration and vividness in the angular gyrus during episodic encoding and retrieval. *Journal of Neuroscience*, *39*(22), 4365–4374. https://doi.org/10.1523/JNEUROSCI.2102-18.2018

Tylén, K., Christensen, P., Roepstorff, A., Lund, T., Østergaard, S., & Donald, M. (2015). Brains striving for coherence: Long-term cumulative plot formation in the default mode network.

NeuroImage, *121*, 106–114. https://doi.org/10.1016/j.neuroimage.2015.07.047

Ursey, W. M., & Henry, J. A. (2015). Visual functions of the thalamus. *Annual Review of Vision Science*, *344*(6188), 1173–1178. https://doi.org/10.1146/annurev-vision-082114-035920.Visual

Utevsky, A. V, Smith, D. V, & Huettel, S. A. (2014). Precuneus is a functional core of the default-mode network. *Journal of Neuroscience*, *34*(3), 932–940. https://doi.org/10.1523/JNEUROSCI.4227-13.2014

Van Ede, F., Board, A. G., & Nobre, A. C. (2020). Goal-directed and stimulus-driven selection of internal representations. *Proceedings of the National Academy of Sciences of the United States of America*, *117*(39), 24590–24598. https://doi.org/10.1073/pnas.2013432117

Vanderwal, T., Eilbott, J., & Castellanos, F. X. (2019). Movies in the magnet: Naturalistic paradigms in developmental functional neuroimaging. *Developmental Cognitive Neuroscience*, *36*. https://doi.org/10.1016/J.DCN.2018.10.004

Wang, C., Stebbins, G. T., Medina, D. A., Shah, R. C., Bammer, R., Moseley, M. E., & deToledo-Morrell, L. (2012). Atrophy and dysfunction of parahippocampal white matter in mild Alzheimer's disease. *Neurobiology of Aging*, *33*(1), 43–52. https://doi.org/10.1016/j.neurobiolaging.2010.01.020

Ward, A. M., Schultz, A. P., Huijbers, W., Van Dijk, K. R. A., Hedden, T., & Sperling, R. A. (2014). The parahippocampal gyrus links the default-mode cortical network with the medial temporal lobe memory system. *Human Brain Mapping*, *35*(3), 1061–1073. https://doi.org/10.1002/hbm.22234

Webb, M. (2009). *500 Days of Summer*. Fox Searchlight Pictures.

Whitney, C., Huber, W., Klann, J., Weis, S., Krach, S., & Kircher, T. (2009). Neural correlates of narrative shifts during auditory story comprehension. *NeuroImage*, *47*(1), 360–366. https://doi.org/10.1016/J.NEUROIMAGE.2009.04.037

Willems, R. M., Nastase, S. A., & Milivojevic, B. (2020). Narratives for Neuroscience. *Trends in Neurosciences*, *43*(5), 271–273. https://doi.org/10.1016/j.tins.2020.03.003

Wu, Y., Wang, J., Zhang, Y., Zheng, D., Zhang, J., Rong, M., Wu, H., Wang, Y., Zhou, K., & Jiang, T. (2016). The neuroanatomical basis for posterior superior parietal lobule control lateralization of visuospatial attention. *Frontiers in Neuroanatomy*, *10*(MAR), 1–9. https://doi.org/10.3389/fnana.2016.00032

Xu, J., Kemeny, S., Park, G., Frattali, C., & Braun, A. (2005). Language in context: Emergent features of word, sentence, and narrative comprehension. *NeuroImage*, *25*(3), 1002–1015. https://doi.org/10.1016/j.neuroimage.2004.12.013