# Examining the Relationship between Story Structure and Audience Response

## How Shared Brain Activity Varies over the Course of a Narrative

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***Abstract:*** When audiences watch a movie, we can examine the similarities among their brain activity via inter-subject correlation (ISC) analysis. This study examines how the strength of ISC (how similarly brains respond) varies over the course of a Pixar short film: specifically comparing this across the exposition, rising action, climax/fall out, and resolution sections of the story. We focus on ISC in the mentalizing network, often linked to social-cognitive processes that are essential to narrative engagement. We find that ISC rises from exposition to the climax. Moreover, we explore this shared response across age groups, finding that ISC is present across age groups, albeit weak in younger children. This approach offers new insights into the brain basis of engagement and story structure.

***Keywords:*** audience engagement, inter-subject correlation, narrative structure, neuroimaging, story processing

Mass media in general, and narratives in particular, can powerfully affect audiences and evoke similar responses among large audiences (e.g., Zillmann 2010). This includes everything from shared reactions to a scary slasher movie to the ability of an inspiring news story to become the talk of the day. However, how to capture these shared audience responses has been a pervasive question (e.g., Bryant and Oliver 2008). Historically, much research has employed self-report measures, but these cannot observe biological responses that occur on a moment-to-moment basis, or those outside of the scope of introspection. The emerging field of media neuroscience emphasizes that the brain is the essential intermediary between message content and media effects, and neuroimaging measures provide

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***Analyzing fMRI data from adults and children watching a Pixar movie demonstrates shared audience engagement (indicated by ISC) as the plot unfolds.***

***In particular, we find:***

- ***Audience brain responses become more similar from the exposition to the story's climax***
- ***This shared engagement remains strong through the story resolution***
- ***Notably, this is true for the mentalizing network associated with social cognition thought to be vital for story processing and comprehension***
- ***Adults and children show broadly similar patterns of activity***
- ***However, the three-to-five-year-olds have less similarity with each other and with other groups***

a way to interrogate brain responses while a movie unfolds (e.g., Hasson, Landesmann et al. 2008).

Over the past decade, numerous studies have shown how biological measurements can support theoretical developments in media research (e.g., Weber et al. 2008). Within this context, an approach called inter-subject correlation (ISC) quantifies the degree to which the brains of audience members who are exposed to the same media exhibit similar or shared neural responses during reception (Hasson, Nir et al. 2004; Hasson, Landesmann 2008; Nastase et al. 2019; Schmälzle and Grall 2020). Previous research has examined ISC over the course of a whole film, demonstrating that narratives command higher ISC (i.e., higher similarity between viewers' brain responses) than CCTV footage (Hasson, Landesmann 2008), and that inspiring and suspenseful narratives result in higher ISC than expositional texts (Grall et al. 2021; Schmälzle and Grall 2020). Yet much of the work using this approach looks at brain-to-brain similarities over the course of an entire narrative rather than examining how particular scenes evoke brain responses, or examines ISC over the whole brain rather than calculating how this similarity might manifest in specific subregions of the brain that are of theoretical interest.

In this study, we examined audiences' shared neural activity over the course of a Pixar short film, specifically in a network of brain regions implicated in social-cognitive processes that are key to following and engaging with narrative content. We (1) replicate studies showing that brain activity is similar across members of a movie audience; (2) examine how this shared activity varies across the act structure of an unfolding plot; and (3) compare patterns of movie-evoked brain similarities between audiences comprising of children and adults.

***Brain Responses to Stories***

Following a story clearly depends on obligatory sensory and perceptual mechanisms (e.g., seeing images or reading/hearing words), but also requires higher-level brain systems related to understanding the actions of the story's characters as well as their reactions to the story events (Boyd 2009). We will skip discussion of the basic visual and auditory systems here and instead focus on the higher-order social and cognitive processes, which are both more germane to why people seek out and enjoy stories and transcend any particular story format. We will therefore sideline many issues of text and film comprehension that center on the specifics of the mode of story transmission and its processing (e.g., in the visual and auditory cortices). Instead, we focus our attention on story content, agnostic to its media form.[2] Here, we take narratives to be sequentially linked events that portray characters with agency and their actions and interactions in some structured and organized plot (Gerrig 1993).

Because stories by definition center on social actors (characters) in social settings (interacting with the world around them), stories are thought to run in the mind like social simulators, playing upon our socially wired proclivities (Grady 2020; Mar 2004, 2011, 2018). Stories are processed via a series of interconnected mental models about the plot, characters, and story world (Busselle and Bilandzic 2008; Magliano and Clinton 2016; Zwaan 1999). To successfully comprehend a narrative and become engaged by it, audience members must track the actions, motives, and emotional states of the characters, implicating several social-cognitive processes, such as perspective-taking, empathy, or the generation of expectations about future actions and events (Alcalá-López et al. 2018; Frith and Frith 2012; Kintsch 1998; Schmälzle and Grall 2020; Sommerville and Decety 2017; Yeshurun, Swanson et al. 2017).

Extant literature demonstrates that processing stories recruits brain regions like the temporoparietal junction (TPJ), the medial prefrontal cortex (mPFC), and the precuneus (Mar 2011). The TPJ, mPFC, and precuneus, together with temporal lobe and subcortex regions, are heavily involved in social-cognitive processes, broadly defined, and they are often collectively referred to as the mentalizing network, especially within social neuroscience literature (Lieberman 2015).

We use the label mentalizing network here, but we note that these regions overlap with the default mode network (DMN) (Raichle 2015). The DMN is associated with several higher-level processes, including self-related cognition, autobiographical memory, or mind-wandering, and recent theoretical work argues that this network integrates extrinsic and intrinsic information over longer timescales to form context-dependent models of unfolding situations (Yeshurun, Nguyen et al. 2021). This role of the DMN in "sense-making" processes is very compatible with empirical findings that show that its subregions, particularly the TPJ, activate during tasks designed to manipulate mentalizing (Schurz et al. 2014) as well as when people process socially engaging narratives (e.g., Jääskalainen et al. 2021; Nguyen et al. 2019; Tikka et al. 2018). As such, this article examines the network of brain regions implicated in a variety of social-cognitive processes over the course of a short narrative film.

## Measuring Shared Brain Responses via Inter-Subject Correlation Analysis

Prior research demonstrates that as people process the same narrative, their brains should exhibit similar brain responses, and this similarity can be measured via the inter-subject correlation technique (Hasson, Nir et al. 2004; Nastase et al. 2019). In essence, this method calculates correlation coefficients between brain activity time series from different audience members. Starting with the basic analysis of the sensory input of media stimuli, it seems clear that brain regions involved in vision should respond somewhat similarly to a movie because the same images are presented to all viewers. Critically, however, since the movie's social content is also the same for everyone, we would also expect that regions like the TPJ or other parts of the mentalizing network discussed above should exhibit similar responses (e.g., Lerner et al. 2011; Chen et al. 2017, for review see Jääska-

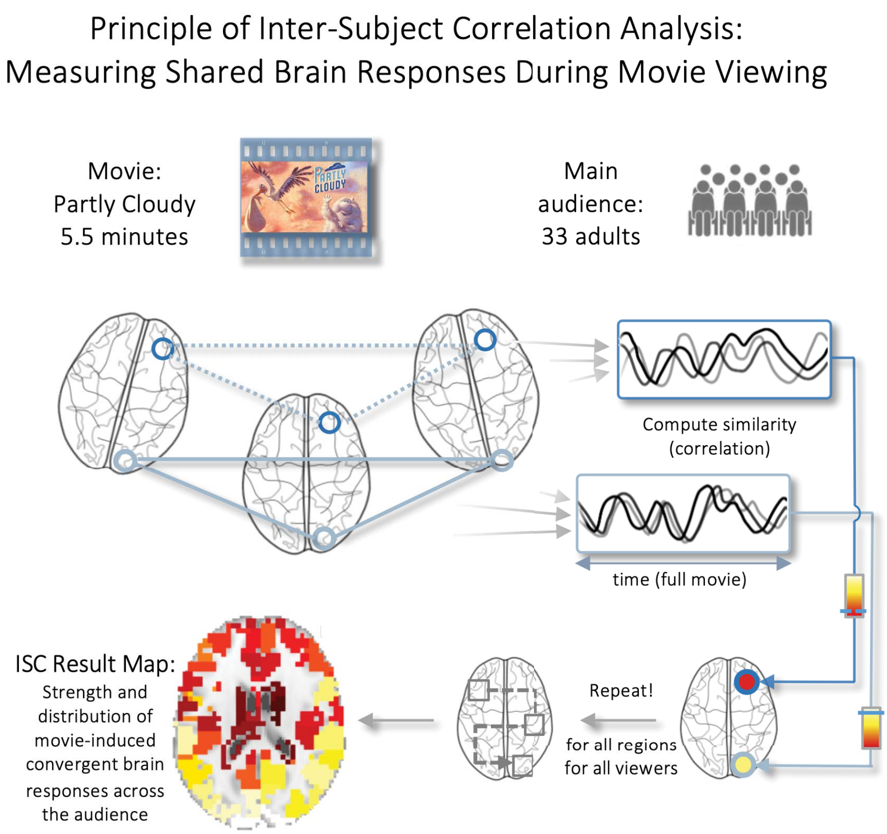



*Figure 1. Inter-subject correlation (ISC) analysis identifies shared brain responses evoked by a visual movie*

lainen et al. 2021; Schmälzle, Wilcox et al. 2022). This reasoning predicts that shared brain responses should emerge while audience members process a narrative:[3]

> **H1:** When watching a (visual) narrative, audiences will exhibit similar brain responses in regions that span from regions involved in basic vision to higher-level regions of the mentalizing network.

Brain activity is captured while audience members view a movie (here Pixar's *Partly Cloudy*, 2009), extracted from individual regions, and compared across viewers. Regional ISC results are color-coded and plotted on a brain map. Thus, the images in this article show how similar brain activity is across audience members, with brighter colors representing more consistent responses.[4]

***Shared Brain Activity during an Unfolding Narrative***

In addition to exposing shared brain responses to an entire narrative, the similar brain responses central to ISC analysis may be used to map dynamic changes in audience engagement over the course of a story's twists and turns (Schmälzle and Grall 2020). Specifically, by computing ISC analyses separately for individual parts of a movie, one can potentially use the approach to tap into the "strength of the grip" a given part of the stimuli has on the audience (e.g., Hasson, Landesmann 2008). This would open the door to address many exciting research questions related to narrative structure and composition, which have long captured the interest of narrative scholars. Indeed, canonical Western conceptualizations of narrative structure point to a common "beginning, middle, end" format. These views date back to Aristotle (trans. 2013) and echo famous figures like Gustav Freytag (1863), Joseph Campbell (1949), and Kurt Vonnegut (1995). While the details of these story models vary, there is broad agreement that stories consist of a series of linked events, involving conflict that unfolds over time and leads toward a final climax and resolution (Gerrig 1993). Freytag's Pyramid is perhaps the most developed of these models and thus served as a starting point for our examination of the relationship between story structure and the collective audience responses identified via ISC analysis. With this in mind, we are interested to see how the shared brain activity varies over the unfolding plot (its exposition, rising action, climax, and denouement), particularly within the brain regions of the mentalizing network discussed above.

Several narrative theories, such as affective disposition theory (Zillmann 2000), excitation transfer (Zillmann 2006), emotional flow (Nabi and Green 2015), and peak-end theory (Redelmeier and Kahneman 1996), imply that a story's structure can modulate audience responses at different points in a narrative. One general observation from entertainment research is that

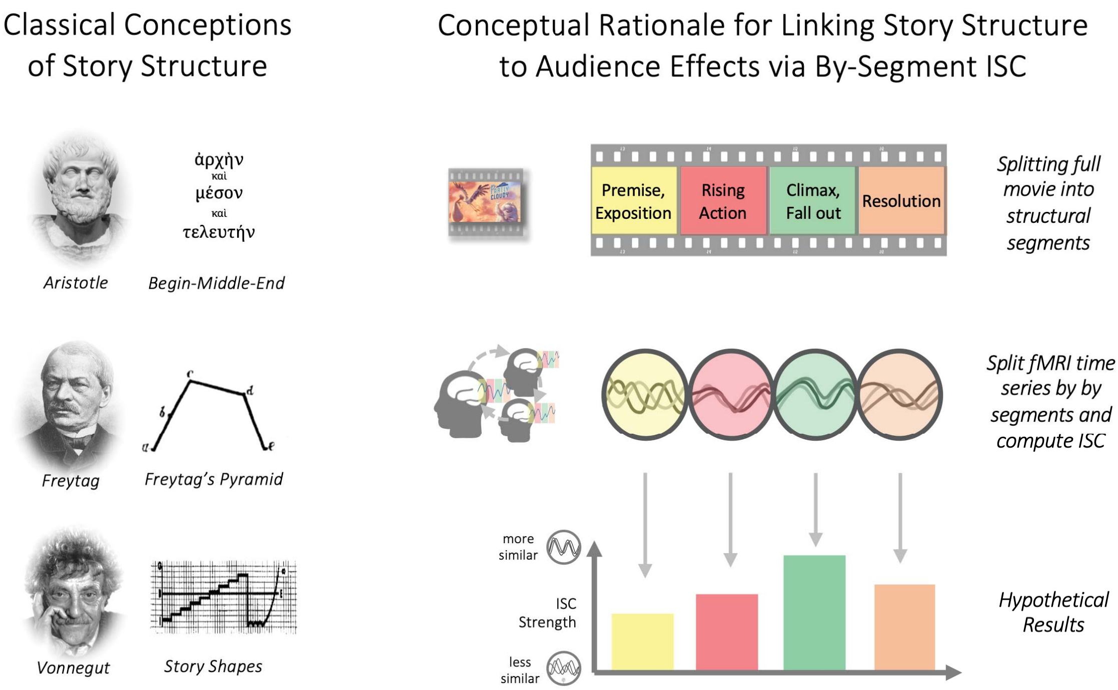



*Figure 2. Connecting story structure to by-segment inter-subject correlation*

*Left panel. Throughout history scholars have noted that stories' structural characteristics vary over time. Although details vary, a consistent implicit idea is that stories have a temporal-structural organization that should affect the audience's response.*

*Right panel. Functional neuroimaging provides a way to capture brain responses during movie viewing. The key idea is to resolve ISC for individual segments as opposed to computing it for an entire movie. Thus, by structurally dividing the story into segments and computing ISC within each segment, we can quantify the strength of shared audience brain responses during the premise/ exposition, the rising action, climax/fall out, or resolution parts, respectively.*

as a story unfolds, audience members may become progressively drawn into the story and generally more engaged (Green et al. 2004; Greenwald and Leavitt 1984; Schmälzle and Grall 2020). We therefore might expect that narrative structure relates to the degree audiences' brain responses converge. If true, then the strength of ISC indices, which measure the shared brain engagement of viewers, should increase over the course of the movie, culminating in the tense moments of a story's climax and immediate resolution. In particular, such variations in ISC strength on the basis of structural characteristics of narratives should be particularly evident within the abovementioned mentalizing network, and some prior work has indeed reported compatible attentional modulations of ISC strength (e.g., Grall et al. 2021; Schmälzle, Häcker, Honey et al. 2015; Yeshurun, Swanson et al. 2017). Thus, we hypothesize the following:

> **H2:** Shared brain activity (ISC) will vary throughout the narrative, in which the premise prompts the lowest levels of shared brain activity within the mentalizing network, followed by an increase in shared brain activity during the exposition, and the climax commanding the highest level of shared brain activity among viewers.

However, if rising tension causes brain activity across the audience to converge, it is unclear what will happen when that narrative tension is resolved. When everyone is interested in the climax, it seems reasonable that everyone would be interested in its fallout, and shared activity would remain high through the denouement. Conversely, we might surmise that once the central tension is resolved, audiences' brains will "decouple" as individuals trend back to their own idiosyncratic thought patterns, reducing coefficients of shared activity as the story winds down. We thus ask:

> **Exploratory RQ1:** Will shared brain activity during the resolution stage of the plot differ from the other parts of the narrative?

### *Comparing Shared Brain Activity between Adults and Children*

As children develop, marked changes occur within their cognitive systems involved in selective attention, language comprehension, social cognition, and numerous other capacities essential to narrative reception (e.g., Decety and Cowell 2016; Johnson and DeHaan 2015). For instance, media research demonstrates that older children are much more likely to recount the motivations of character actions than younger children (e.g., Surber 1982; Wartella and Alexander 1978) and successfully infer characters' emotional states (see Hoffner and Cantor 1991). This naturally raises the question of how brain responses that underpin these media reception processes may vary as children develop. Notably, several recent studies have already examined shared audience brain responses to examine children's developmental trajectory of social cognition or processing differences associated with clinical diagnoses (Cantlon and Li 2013; Glerean et al. 2016; Hasson, Avidan et al. 2009; Richardson et al. 2018). Yet, this work tends to focus on general cognitive and clinical aspects of maturation rather than the nexus between development and narrative processing.

Therefore, we will also explore the role of age on our predictions above, particularly for younger children (known to have less developed social-cognitive skills) and older children (who reliably perform as well as adults on many social-cognitive tasks such as theory of mind tests, see Richardson et al. 2018). From a media processing perspective, young children may therefore respond differently to socially driven story content than more mature audiences. However, it is unclear whether younger children would have high shared neural activity, comparable to more mature audiences, or whether shared neural activity might be generally lower because young children may exhibit attention fluctuations, more idiosyncratic processes, and so forth (see Fisher 2019; Piazza et al. 2021).

> **Exploratory RQ2:** Will shared neural activity within the mentalizing network differ between adults and children in different parts of the narrative?

### *The Present Study*

The current study examines how a movie engages the brains of viewers in a similar way, as evidenced by correlated brain responses across recipients (using inter-subject correlations, or ISC). We leveraged an open neuroimaging dataset in which a large audience's brain activity (*n* = 155) was recorded while people viewed a short, animated film depicting a social narrative about two friends (Richardson et al. 2018). Moreover, the sample covered an age range from very young children up to adult viewers. To test the hypotheses and research questions introduced above, we first examined adult participants' ISC throughout the whole movie, and then subsequently quantified the strength of ISC (i.e., the degree of between-viewer brain similarity) during separate parts of the narrative. We assessed ISC for each of 268 individual brain regions and zoomed in specifically on the mentalizing network defined above because of its putative involvement in story processing and social cognition more broadly. Finally, we compared ISC between audiences comprising adults and children, the latter being further divided by developmental age bracket.

## Methods

In this study, we analyze a public dataset (OpenNeuro #ds000228) that contains fMRI recordings from a sample of adults and children watching a Pixar short film (Richardson et al. 2018). Below, we provide only a short description of the original dataset's most relevant methodological features and a more in-depth description of our own procedures.

### *Sample*

The sample (*n* = 155) included 33 adults ranging from ages 18 to 39 (20 female; $M_{age}$ = 24; $SD_{age}$ = 5), and 122 children (64 females). In our analysis, we binned children into three age brackets, ranging from 3 to 5 ($n_{young\ children}$ = 31), 5 to 8 ($n_{middle\ aged\ children}$ = 57), and 8 to 13 years ($n_{older\ children}$ = 34), with a hard upper bound such that a child who was 5 years and 3 months old would be binned in the middle bracket. These bins were specified in line with developmental literature suggesting mentalizing processes mature in toddlerhood and are fully functioning by age five, and that children over age eight process media content and narrative characters more like adults than their younger counterparts (Hoffner and Cantor 1991; Richardson et al. 2018).

#### *Movie Stimulus*

All participants viewed a silent version of the animated Pixar short film, *Partly Cloudy* (2009, 5.6 minutes). The film explores the bond of friendship and loyalty between a storm cloud and his loyal but long-suffering delivery partner, a stork named Peck.

#### *Movie Segment Coding*

Five coders annotated the film into five acts, using a descriptive codebook drawing from Freytag's (1863) pyramid and other sources to note the time of each act break. While intercoder agreement was high (Krippendorff's α = .984, using ReCal-OIR; Freelon 2013), an exact timestamp was required for each act break to uniformly segment the brain data. Final timestamps were selected by an a priori analysis plan based on majority rule and averaging equivalent responses (within +/- 5 seconds across coders). Although the codebook was based on a traditional five-act structure, two concerns became apparent during this process. First, differentiating the climax of a story and its immediate outcome was difficult to parse in such a short film and led to some intercoder disagreements. We, therefore, collapsed two of the coded acts, climax and fallout, into one story segment resulting in four story segments (see figure 3).[5] This had the added benefit of increased statistical power, as there is only one full-brain scan every two seconds, and fewer, longer story segments would be more robust for our temporally-based analysis plan. While we acknowledge this segmentation of narrative structure is relatively rudimentary compared to the nuanced rhetorical structures debated by narratological scholars, it is to our knowledge one of the first attempts to unite neural measures of audience response and traditional tenets of narrative theory.

#### *fMRI Acquisition, Processing, and Inter-subject Correlation Analysis (ISC)*

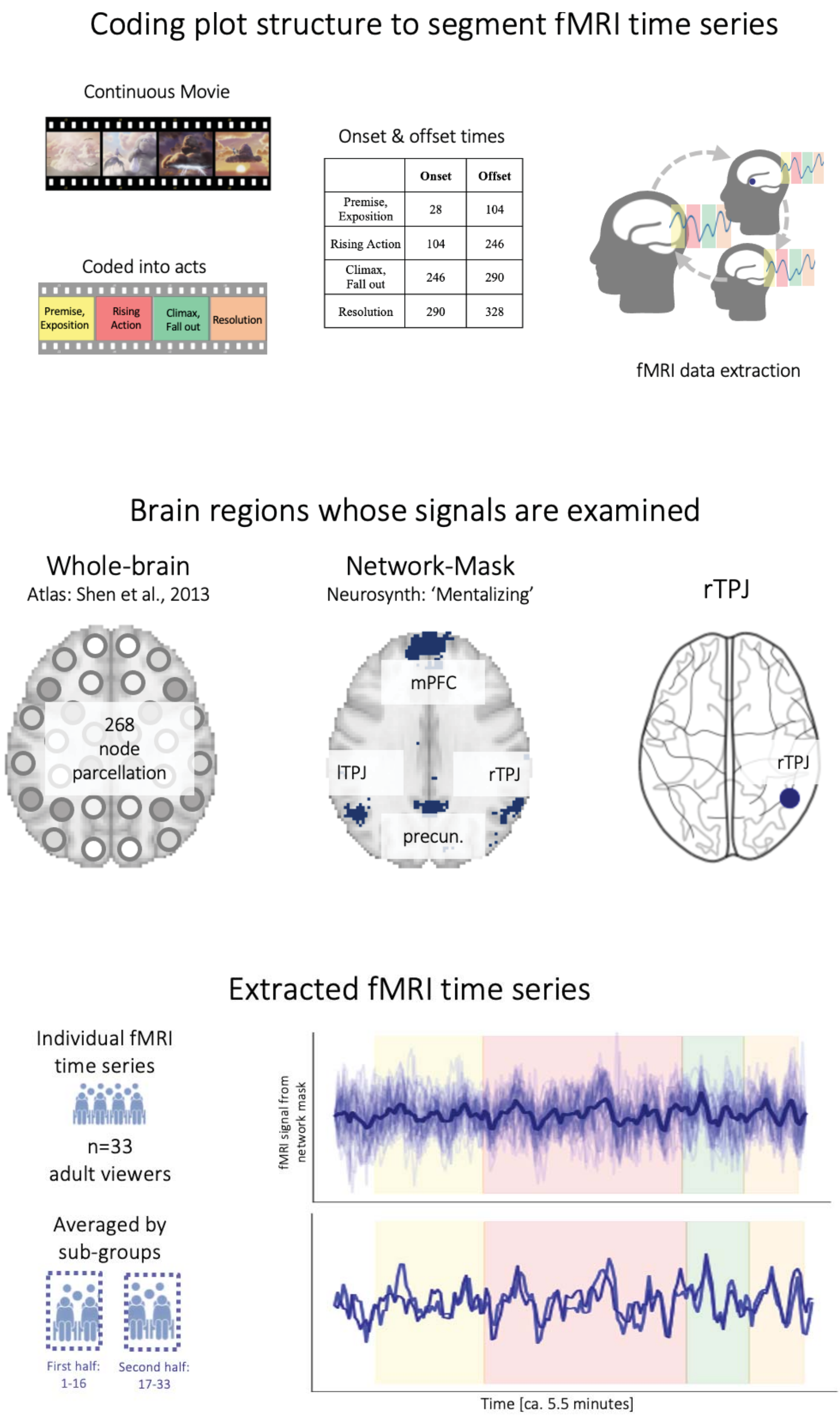
We document the analysis pipeline in the form of reproducible Jupyter-notebooks in the study's online repository: https://github.com/nomcomm/ISC_StoryStructure_Projections. Additional methodological details on fMRI acquisition procedures can be found in the original study (Richardson et al. 2018).[6] In brief, fMRI data were recorded continuously while participants viewed the movie with a TR of 2 seconds, yielding 168 volumes that correspond to a movie duration of 336 seconds (5 minutes, 36 seconds). Preprocessed data were downloaded and our own analyses of these data were then carried out using functions from the nilearn and BrainIAK packages (Abraham et al. 2014; Kumar et al. 2020) and in-house code.

The fMRI data recorded during viewing were high-pass filtered at 0.01 Hz, detrended, and standardized regional brain activity time series were extracted. Specifically, we extracted data at three levels of granularity, starting with a whole-brain parcellation encompassing 268 regions, then from the mentalizing network (masks specified below), and finally from the rTPJ subregion of this network. These data extraction steps are described next.

First, we extracted and examined brain activity time series from the entire brain using the 268-parcel atlas provided by Xilin Shen and colleagues (2013). This resulted in a 168 (time points) * 268 (regions) matrix for each of the 155 participants. Next, as our hypotheses focused specifically on the mentalizing network associated with a range of social-cognitive processes, we identified this system via a term-based NeuroSynth meta-analysis. Specifically, we downloaded a meta-analytic map for all studies associated with the term mentalizing in the NeuroSynth.org database (see figure 3; Schmälzle, O'Donnell et al. 2017; Yarkoni et al. 2011) and extracted brain time series from all voxels that fell within this mask, resulting in a single vector of 168 timepoints. As expected, the meta-analytic mentalizing map was very similar to the well-known default mode network (e.g., Yeshurun, Nguyen et al. 2021). Finally, we focused particularly on the right temporo-parietal junction (rTPJ), a region that has long been associated with social-cognitive processes (Mars et al. 2012; Schurz et al. 2014). Thus, we also extracted the brain activity from the rTPJ in isolation (168 timepoints from the rTPJ).

These extracted brain activity time series were then submitted to intersubject correlation (ISC) analysis (Hasson, Nir et al. 2004; Hasson, Malach et al. 2010) to map out how similarly brain responses unfolded across viewers in (1) the whole brain, (2) the mentalizing network, and (3) the rTPJ specifically. The conceptual procedure of ISC analysis is illustrated in figure 1, and a methodological overview is provided by Samuel Nastase and colleagues (2019). In brief, ISC analysis computes the Pearson correlations between brain activity time series across corresponding regions from separate brains.

Specifically, the input to ISC analysis are the extracted brain time series from all viewers (or subgroups), and the resulting ISC coefficients index how similarly a given brain region responds to the movie across the audience (or sub-audience). To carry out ISC analysis, we used the ISC-functions implemented in the BrainIAK package, which have been described in a recent methodological review (Nastase et al. 2019), and we provide the code for these analyses online. Another methodological detail worth mentioning is the distinction between the so-called leave-one-out (LOO) and pairwise ISC analysis. In general, we used the LOO approach as the primary method, except for comparisons of ISC across subgroups (e.g., adults versus children) that will be indicated.[7]




| | Onset | Offset |
|---|---|---|
| Premise, Exposition | 28 | 104 |
| Rising Action | 104 | 246 |
| Climax, Fall out | 246 | 290 |
| Resolution | 290 | 328 |

*Figure 3. Plot coding, brain regions investigated, and fMRI signal inspection*

*Top panel. Coding the plot into acts yields on- and offset times for each act, which are used to split the continuous fMRI time series into segments corresponding to viewing each act.*

*Middle panel. fMRI data were extracted at three levels of granularity. First, we extracted data from 268 individual regions that span the entire cortex, yielding 268 regional time series. Next, as the focus of our investigation was on the so-called mentalizing network, which overlaps with the default mode, we used a mask to extract data from regions that fall within this network mask.*

*Finally, we also zoomed in on the temporoparietal junction (TPJ) as well as other regions within this network.*

*Bottom panel. Inspecting the raw fMRI time series (here from the network-mask) reveals that the continuous brain signals exhibit similarities across viewers, which become especially visible once data are averaged.*

### *Static and By-Segment ISC Analysis and Analysis within Age Groups*

In the past, ISC analysis has typically been carried out using the fMRI time courses corresponding to a movie in its entirety (Hasson, Landesman et al. 2008; Schmälzle, Häcker, Renner et al. 2013; Wilson et al. 2008). The resulting ISC map, called *static ISC*, refers to the degree of brain response similarity throughout the entire movie. To address H1, we computed this static ISC analysis for each subgroup of the audience (i.e., separately for adults and each age bracket of children).

In addition to the static ISC analysis (addressing H1), we also examined ISC for each of our coded movie segments (addressing H2 and RQ1). Moreover, we additionally examined this by-segment ISC across the different age subgroups (RQ2). Thus, we computed ISC in the mentalizing system among the adult subgroup for the entire film, and then separately for the segments corresponding to the premise, rising action, climax/fall out, and resolution. Specifically, we began with the sample of adults ($n_{adults}$ = 33) and submitted the fMRI time courses for each plot segment to ISC analysis (see above and figure 3).[8] We then examined the brain responses of children for the same movie segments, examining older children (8–12 years), middle children (5–8 years), and very young children (3–4 years) separately. For further details see the supplementary methods and reproducibility package in the study's online repository.[9]

## Results

### *Shared Audience Brain Responses during Media Reception (H1)*

First, to demonstrate that the brains of viewers exposed to the same movie respond in an inter-subjectively similar way, we computed inter-subject correlation analyses for the entire movie (168 TRs in a static ISC analysis). The results are shown in figure 4, revealing that movie viewing evokes shared responses among audience members (ISC) throughout the brain. As expected, the inter-subject similarity of brain activity time courses is strongest in visual regions (e.g., $r$ = 0.55 in the visual cortex for the leave-one-out (LOO)-ISC-analysis; $p < 0.001$, FDR-corrected[10]), and much lower for primary auditory regions (e.g., $r$ = 0.147), which is well in line with the visual nature of a silent movie.[11]

The spatial distribution of ISC effects across brain regions corresponds well with that of previous reports (Hasson, Nir et al. 2004; Lahnakoski et al. 2014; Schmälzle, Häcker, Renner et al. 2013). Importantly, we find that robust ISC (indexing similar brain activity across audience members) extends into higher-order regions involved in salience processing, executive control, and—most importantly—into the mentalizing network pertinent to our hypotheses: ISC across the network outlined in blue in figure 4 as a whole

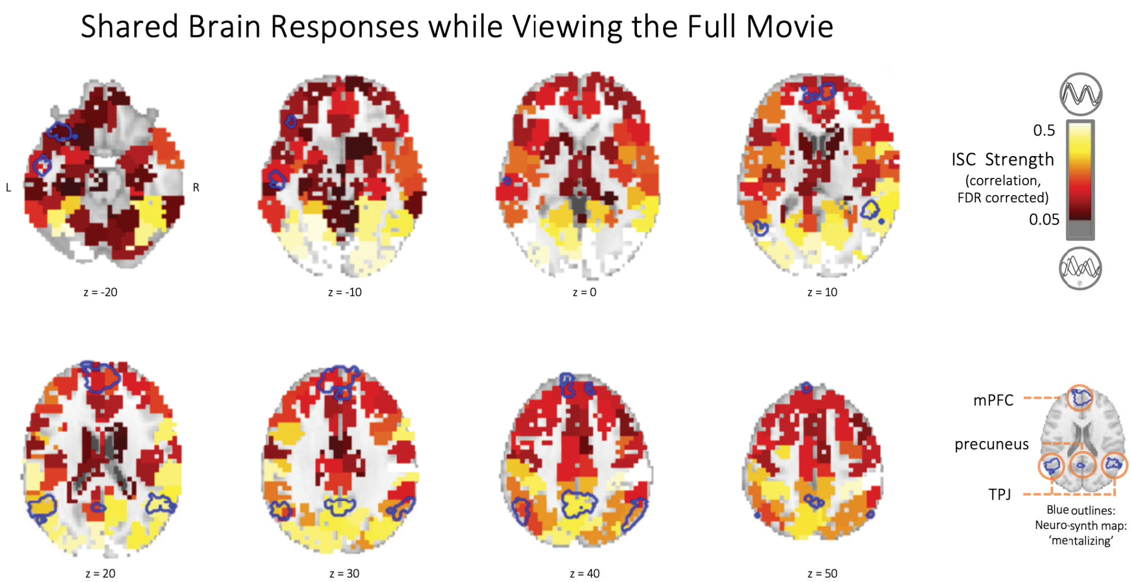



*Figure 4. ISC results during the entire movie*

*These maps display the static ISC for the entire movie among the audience comprised of adults. As can be seen, the movie prompted strong and reliable ISC throughout the brain, strongest in visual regions, but still strong and statistically significant in the regions outlined in blue, which represent the so-called mentalizing network as defined by NeuroSynth meta-analysis (this network overlaps with the well-known default mode network, see Yeshurun, Nguyen et al. 2021)*

is clearly positive and significant (*ISC* = 0.295, $p < 0.001$, FDR-corrected). Similarly, computing this analysis for selected regions of the default mode/mentalizing network (as defined by the Shen parcellation and confirmed by their overlap with the NeuroSynth-based map for mentalizing—see repository for details): $ISC_{right\ TPJ} = 0.3$, $ISC_{left\ TPJ} = 0.353$, $ISC_{medial\ prefrontal\ cortex} = 0.245$, and $ISC_{precuneus} = 0.374$ (all *p's* < 0.001, FDR-corrected). In sum, these results show that the short Pixar movie-evoked brain responses that are similar and thus collectively shared among viewers, and this similarity was specifically observed in regions of the mentalizing network. It is important to note, however, that these similarities refer to the entire 5.6-minute film, that is, they represent static ISC results. Having established that we find robust static ISC over the movie as a whole, we next zoomed in on specific story segments to examine how ISC might vary between structural story segments.

### *Analysis across Different Story Segments (H2 and RQ1)*

We next examined how ISC varied among our delineated narrative segments, again specifically zooming in on brain responses within the network of interest, the mentalizing network. To this end, we extracted the fMRI data from the network-mask as a whole as well as from individual subnodes, particularly the rTPJ (see Methods and figure 3). We divided the time series based on our coded plot segments (premise, the rising action, the climax/fall out, all relevant for H2, and the resolution, for RQ1), and then examined these shorter sections via segment-wise ISC analyses.

As shown in figure 5, by-segment ISC within the mentalizing network nominally increases over the first three narrative segments, up to and including the story's climax ($ISC_{Premise} = 0.182$, $ISC_{Rising\ Action} = 0.354$, $ISC_{Climax/Fallout}$ =

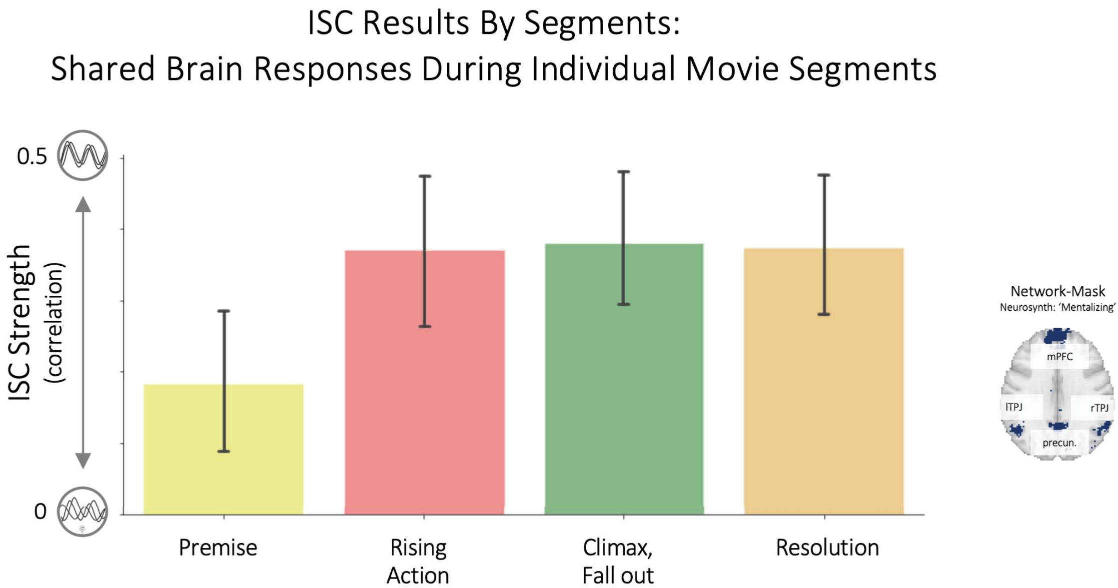



*Figure 5. Result for the by-segment ISC analysis for the adult group*

*The height of the bar plot indicates ISC strength within each segment, whereby ISC was computed across the extracted fMRI time series from the network-mask*

0.363). In principle, one could argue that the general pattern of by-segment ISC can be of interest even without testing for significance between consecutive segments (i.e., if one viewed by-segment ISC as a group-level metric of audience engagement during parts of a narrative whose gestalt is important). However, given that we postulated an increase in ISC, this does call for statistical comparisons. Testing for differences between the ISC during successive segments via nonparametric permutation testing, we find that the increase in ISC from the premise to the rising action is statistically significant ($p$ = 0.003), which is in line with H2. However, the small nominal increase from the rising action to the climax phase ($ISC_{Rising\ Action}$ = 0.354 to $ISC_{Climax/Fallout}$ = 0.363) is not statistically significant ($p$ = 0.79). Thus, although the results are generally in line with H2, the pattern is not fully supported.

Next, the exploratory research question (RQ1) concerned ISC during the resolution phase, after the story's climax has been resolved. Here, we see a slight drop in nominal ISC from a level of $ISC_{Climax/Fallout}$ = 0.363 to $ISC_{Resolution}$ = 0.357, though statistical testing revealed that this is not statistically significant ($p$ = 0.96).

Next, we zoomed in on the rTPJ as the region that has been most often associated with mentalizing and related social-cognitive processes in prior literature. The rTPJ reveals a slightly different pattern of shared activity ($ISC_{Premise}$ = 0.213, $ISC_{Rising\ Action}$ = 0.391, $ISC_{Climax/Fallout}$ = 0.262, $ISC_{Resolution}$ = 0.259). In the rTPJ, ISC is highest during the rising action of the narrative but plateaus in a way that diverges from the mentalizing network as a whole. While the overall network trend is as anticipated, this difference is of particular note.

### *ISC during Movie Viewing across Age Groups (RQ2)*

Finally, to examine the consistency of these findings across age groups, we carried out ISC analyses for three age bands (older children: 8 to 12 years old; middle aged children: 5 to 8 years old; young children: 3 to 5 years old) and compared these to an adult sample. Figure 6 shows the results of this analysis. As can be seen, the ISC effects are expressed in a similar fashion in the four independent age groups. To quantify this similarity, we correlated the spatial pattern of ISC results (i.e., group-wise vectors of 268 regional ISC values). This analysis revealed that the spatial pattern of ISC is highly similar between adults and older children ($r(266) = 0.91$, $p < 0.001$), and all other correlations between adult and children (old, middle, young) groups and within the subgroups of children also exceeded $r(266) = 0.84$, $p < 0.001$.

Inspection of figure 6 also suggests that the adult audience exhibits the highest level of ISC and the average level of ISC supports this observation (mean across all 268 brain regions: $ISC_{adults} = 0.21$, $ISC_{older\ children} = 0.19$, $ISC_{middle\ aged\ children} = 0.18$, and $ISC_{young\ children} = 0.12$, note that these values reflect pairwise ISC analysis instead of the LOO-based method to avoid bias due to unequal group sizes). To formally test for group differences in ISC strength, we compared the regional level of ISC between groups. In the lateral occipital cortex, for instance, where ISC for visual movies is typically strongest, we find the strongest ISC for adults compared to all other groups ($ISC_{adults:ISC,\ pairwise} = 0.30$, $ISC_{older\ children} = 0.13$, $ISC_{middle\ aged\ children} = 0.088$, $ISC_{young\ children} = 0.09$; *Kruskal-Wallis* $H = 761.71$, $p < 0.001$); similar results were obtained for the majority of brain regions (ISC for adults is strongest for 100 out of 182 regions where differences are significant—see repository). While we did not formally test for an age-gradient, the strength of ISC appeared to decrease in younger groups (e.g., the youngest groups never exhibited the highest ISC among the groups among 182 regions that showed statistically significant differences). Taken together, these findings suggest that while all groups exhibit the expected spatial distribution of ISC across the cortex, responses seem to be more idiosyncratic (lower ISC) among the younger audiences.

Next, zooming in again on the mentalizing system specifically, ISC is observed across age groups, albeit less clearly for the youngest kids. This was again examined by computing ISC for the mentalizing network as a whole and then individually for individual subnodes (rTPJ, lTPJ, mPFC, precuneus). Again, for the system as a whole, we find significant ISC in each group (i.e., *ISCs* = .29, 0.27, 0.3, and 0.2 for adults, older, middle, and young children, respectively;[12] all *ps* < 0.001, FDR-corrected).

Finally, running these analyses also for individual nodes, particularly the rTPJ, revealed the same pattern of results $ISC_{right\ TPJ,\ adults} = 0.3$, $ISC_{right\ TPJ:\ older\ children} = 0.32$, $ISC_{right\ TPJ,\ middle\ aged\ children} = 0.325$, $ISC_{right\ TPJ,\ young\ children} = 0.168$, *all ps* < 0.001,

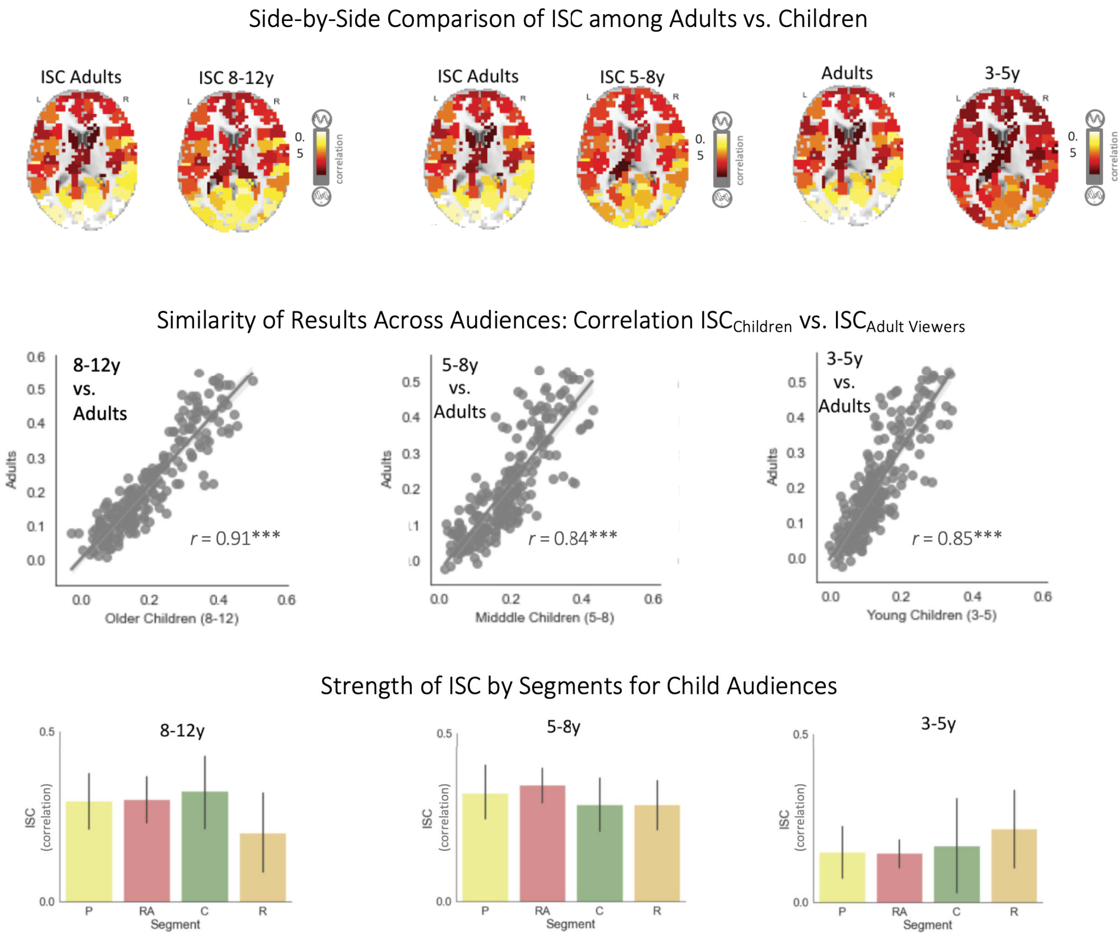



*Figure 6. ISC results for different age groups*

*Top row. ISCs among adults and older, middle, and young children show a highly similar pattern of movie-induced static ISC, although responses are more variable among the younger children.*

*Middle row. Scatter plots demonstrating the high correlation between the cortical distribution of ISC values for adults and all three child audiences.*

*Bottom row. By-segment ISC within the mentalizing network for child audiences (see figure 5).*

FDR-corrected).[13] In sum, we find that in the brain regions comprising the mentalizing system, shared audience brain responses are present even in the youngest audiences, albeit at a slightly lesser degree for the youngest viewers.[14]

## Discussion

The current study used existing fMRI data of an audience watching a Pixar short film to examine the shared brain activity of audience members across the whole brain and in a network of brain regions associated with social-cognitive processes. We examined how collective engagement (as indicated by ISC) may vary (a) over the course of the story's unfolding plot and (b) across age groups. The general findings are in keeping with previous ISC literature, and show that viewers' brain response patterns resemble each other—not only across the whole brain and in visual processing regions, but also in higher-order brain regions that have often been implicated in story processing and social cognition, broadly defined.

The unique contributions here are twofold. First, to our knowledge, this is the first attempt to examine how brain activity tracks with formal conceptions of narrative structure as a framework for audience engagement. Second, we see preliminary evidence that regions comprising the mentalizing network (which significantly overlaps with the default mode) exhibit differential brain activity during a socially focused story for audiences of different ages.

When we look at the segmented plot, ISC analysis indicates that narratives increasingly align the brain activity of individual audience members, suggesting collectively shared engagement with the story increases as the plot unfolds. We emphasize that the term *shared engagement* here refers to the observable brain response evoked during reception of the movie content, and we cannot know whether viewers also had shared cognitive or affective experiences because no data about this were available. However, empirically we find that within a network of regions associated with social cognition and story processing, the audience's brain responses are less correlated as the premise, plot, and characters are introduced, but shared processing (i.e., correlations between viewers' brain activities) increases over the course of the rising action. This culminates in the strongest inter-subject correlations during the climax of the narrative. This alignment of brain activity across audience members is roughly maintained through to the end of the story, though this may be owing in part to the short duration of our stimulus.

While significant additional work is needed to replicate these findings with other films and other audiences, this preliminary evidence is encouraging. Our analyses indicate that activity within the mentalizing network of many audience members seems to become more aligned as the plot unfolds, and most aligned in the climactic moments of the film. Though it should be noted that while we see this across the meta-analytically defined mentalizing network, we do not see this exact same pattern in the rTPJ (here, audiences are most aligned during the rising action). The rTPJ region has historically been most consistently associated with social cognition, and the differential patterns of activation within this region and the mentalizing network as a whole warrant additional exploration. In sum, while our results suggest that by-segment ISCs are a promising approach to examine the relationship between story structure and audience responses, generalization to other stimuli and larger audiences will still be needed going forward.

When we look across age groups, prior psychological literature clearly demonstrates that both social cognition and story comprehension skills develop as children mature. The current results demonstrate that the neural responses during online story processing are relatively similar between adults and children, but on a more granular level, younger children are, in some ways, an audience unto themselves. On its surface, this may be unexceptional (as the primary data collectors noted, helping small children stay still in a scanner can be a challenge; Richardson et al. 2018). However, as developmental psychologists and media scholars both seek to understand what children pay attention to and what they glean from the deluge of media content to which they are exposed, neural evidence is a key factor in message processing, particularly in regions of the brain associated with social cognition (including perspective-taking and empathy) that can be a valuable first step in illuminating how stories capture the minds of audiences and what influence this may have on subsequent processing as children develop.

Understanding how age-related developmental factors influence social processing and narrative engagement is particularly relevant to cultivation research (Gerbner et al. 1986) and other social-cognitive theories (e.g., Bandura 1994) seeking to explain how media portrayals may influence children's real-world behaviors and expectations. The ages at which modeling narratives are most effective and the limits of these interventions is a fruitful area of scholarship (e.g., Mares and Pan 2013; see Cantlon and Li 2013, for an ISC-based study examining *Sesame Street* from a cognitive-developmental perspective).

For media scholars more broadly, demonstrating the potential links between the continuous brain activity recordings and foundational constructs like narrative engagement and involvement is a promising avenue for future inquiry. Researchers have long struggled to clearly describe and measure these processes in order to explain their mechanisms (Hofer 2016). Recent developments in social and affective neuroscience have begun to shed light on the biological mechanisms of psychological processes that underpin media consumption. Examining narrative processing via passive dynamic data collection of real-time brain activity is thus a valuable tool in our arsenal, and one that speaks to a host of theoretical topics that have proven difficult to resolve using verbal-introspective methods. We hope that the current approach may, in time, contribute to longstanding questions about mental models of story processing, narrative involvement, engagement, and persuasion. Likewise, from a practical perspective, understanding how and when stories command collective engagement is a tool that could help measure audience responses and aid message optimization strategies.

***Strengths, Limitations, and Future Directions***

As with any study, a number of limitations need to be acknowledged. First, we used secondary data to compile these analyses. This naturally limits the questions we could ask, the scale of our analyses, and some of the initial data cleaning procedures undertaken. While we are grateful for access to rich datasets that are difficult and costly to compile, the secondary nature of this study restrained our ability to select stimuli and prevented us from examining important questions regarding story comprehension or entertainment experiences (e.g., what did kids take away from the story, had they seen it before, etc.). Integrating neural data with behavioral (e.g., Magliano and Zacks 2011) and experiential measures (Schmälzle and Grall 2020) would be a valuable next step in such inquiries. Similarly, examining ISC across traditional narrative segments provides insight into story processing, however, it is worth noting that we used data from short film viewing and not other narrative formats. We hope that future work will look at the important contributions of a film's formal features and the specific cognitive processes implicated in film comprehension using similar methods to shed further light on the role that content features play in these processes across a variety of media formats and platforms.

Second, while the potential for theoretically derived content analysis to inform neural analyses is promising and relatively novel, some methodological questions and uncertainties remain, particularly regarding time-resolved ISC analyses and the ability to disentangle physical stimulus properties from social-cognitive content elements.

Third, we acknowledge our coding scheme for identifying segments of a narrative was rudimentary, and that this analytical approach could be implemented in a variety of different ways. Therefore, others should continue to explore additional approaches for specifying content structures (for example, via event segmentation; Zacks, Speer, Swallow et al. 2010) in relation to narrative processing and neural activity.

Finally, this analysis assumed minimal structural differences among the brains of our various age groups. This is not without merit (see Richardson et al. 2018), however, experience and skill can materially alter neural architecture (Maguire et al. 2006). As such, there may be topological differences in mentalizing regions as these capacities develop throughout childhood. Therefore, more nuanced anatomical modeling and normalizing parameters among age groups would increase confidence in these findings.

Despite these areas for improvement, the current study has several strengths. From a media studies perspective, rich, realistic, and popular content such as Pixar movies is an ideal testing ground for a real-world audience and media processing and effects. Popularity and viewer figures can be taken as a global metric of public appeal, and continued research into the online processing of media content should prioritize highly engaging, age-appropriate content in this way to further examine the neural substrates of audience appeal and engagement (Dmochowski et al. 2014). From a design perspective, social cognition has traditionally been assessed through verbal tests. Yet Hilary Richardson and colleagues (2018) demonstrate that the neural bases for social cognition show preferential activation even in children who consistently fail traditional false-belief tasks. In which case, passive measures of neurocognitive processes and non-verbal but highly social stimuli, such as those used here, are a necessary and promising direction for developmental inquiries, particularly as they relate to message processing and their implications for observational learning.

## Conclusion

Here we examined how the brains of adults and older, middle, and younger children tune in to an engaging movie about social relationships. The results reveal that the brains of viewers become rather strongly aligned during the reception process, including within the mentalizing network. We see that this alignment of neural processes occurs similarly for adults and children, though the youngest children are slightly less aligned with each other than is observed with older audiences. We also examined whether the collectively shared brain responses can be used to examine the engrossing capacity of an unfolding plot. We find preliminary evidence that ISC increases over the exposition and peaks at the story's climax. However, again we emphasize that more work is needed to test the generality of these findings across audiences, movies, and analytic strategies. In sum, the current approach lies truly at a crossroads of disciplines and opens up new possibilities for research on the neural processes that are key to the reception and effects of engaging narratives.

## Research Transparency Statement

Data used in this work were obtained from the OpenNeuro data repository (ds000228) and code documenting the analyses is accessible online at https://github.com/nomcomm/ISC_StoryStructure_Projections.

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## Notes

[1] The first two authors contributed equally to this article.

[2] While prior literature has established several cognitive processes inherent to film comprehension (e.g., Magliano et al. 1996; Zacks, Speer, and Reynolds 2009), we feel it is important to note that this article is not testing film processing specifically. Rather, it examines shared processing of narrative content (admittedly using a film stimulus). Notably, several studies have demonstrated that comprehension and recall are remarkably similar across audiences of the same narrative in different formats (Baggett 1979)—and more pertinently to the data used here, neural activity is also similar across audiences of the same narrative, including listeners hearing a story in different languages (Honey et al. 2012) and recipients of the same story in alternative formats (Tikka et al. 2018).

[3] Importantly, to prevent any misunderstanding, we want to clarify that this hypothesis refers only to similar brain responses (as captured via fMRI)—and makes no claim regarding the relationship between this observed neural activity and subjective experience. It is also important to clarify that observing different brains that respond similarly to the same content does not mean that they all respond in exactly the same way. Rather, it is well known that there are important individual differences in how people process narratives, although there are also substantial commonalities in audiences' cognitive responses and experiences (as demonstrated by similar inferences drawn during specific story moments, agreement about structural boundaries, or converging predictions about future events; e.g., Magliano et al. 1996; Zacks, Speer, and Reynolds 2009). For instance, visual narrative comprehension is predicated on one's developmental stage and cultural background (Cohn 2020).

[4] Note that this interpretation is considerably different from other ways of analyzing and visualizing fMRI data: The figures in this article represent the consistency of continuous brain responses across multiple viewers. By contrast, often-seen fMRI activation maps focus on how specific stimulus characteristic prompt discrete brain activations.

[5] A brief description of the segments is as follows: *Premise/Exposition:* Clouds produce babies, storks deliver them. *Rising Action:* Gus, the cloud, makes "dangerous" babies. The babies hurt Peck, the stork. *Climax & Fall out:* Peck leaves for another cloud, Gus is very sad. *Resolution:* Peck returns to Gus, carrying protective gear. They reunite.

[6] "ISC_StoryStructure_Projections." *Github*. https://github.com/nomcomm/ISC_StoryStructure_Projections (accessed 3 September 2022).

[7] In the LOO-method, each individual brain response time series is correlated against the average of the rest of the group, repeating this procedure for every audience member, and then averaging the results. In the pairwise method, by contrast, each individual's brain activity time series is correlated against another viewer's brain activity, and the results from all these pairwise computations are then averaged. The LOO-method is faster and more robust against outliers, but if groups differ in size (e.g., adults versus young children), then the LOO-method is biased to yield higher ISC in the larger group. Thus, while we will report LOO-based results as the default, comparisons of ISC between groups will utilize the pairwise method.

[8] These onset times were shifted by 7 TRs (or 14 seconds) to accommodate the natural delay in the brain's hemodynamic response function (~ 2 TRs) and because the in-scanner movie presentation started after a black screen lasting for 10 seconds (5 TRs).

[9] "ISC_StoryStructure_Projections." *Github*.

[10] Results are significant when tested against the null hypothesis that there is no similarity (ISC) across audience brains, as demonstrated by comparing the observed ISC for each region against a null distribution of ISC under no-alignment conditions that were simulated via a random phase-shift permutation analysis (1,000 permutations) (Nastase et al. 2019).

[11] This value is still different from zero, however, as brain systems do not work in isolation and there may be an interaction between attention to the story and scanner noise. However, in prior work using spoken narratives there is much higher ISC in auditory and language-related regions than is seen here.

[12] And we find the same conclusion for pairwise analyses, which result in lower levels of ISC but are unbiased against differences in group size.

[13] Adults (see above) $ISC_{right\ TPJ\ =}$ 0.3, $ISC_{left\ TPJ}$ = 0.353, $ISC_{medial\ prefrontal\ cortex}$ = 0.245, and $ISC_{precuneus}$ = 0.374; Older Children: $ISC_{right\ TPJ}$ = 0.32, $ISC_{left\ TPJ}$ = 0.285, $ISC_{medial\ prefrontal\ cortex}$ = 0.195, and $ISC_{precuneus}$ = 0.427; Middle Children: $ISC_{right\ TPJ}$ = 0.325, $ISC_{left\ TPJ}$ = 0.26, $ISC_{medial\ prefrontal\ cortex}$ = 0.204, and $ISC_{precuneus}$ = 0.394; Young Children: $ISC_{right\ TPJ}$ = 0.168, $ISC_{left\ TPJ}$ = 0.203, $ISC_{medial\ prefrontal\ cortex}$ = 0.113, and $ISC_{precuneus}$ = 0.258. These values reflect ISC-measures based on LOO-analyses and are thus slightly biased by sample size, but the results were also confirmed using pairwise ISC analysis.

[14] While clearly these findings cannot clarify all questions regarding the functional significance of these regions, it does demonstrate that brains of different audience age groups respond to content-driven factors consistently and in ways that can be objectively quantified. Of note, we want to reemphasize that these results refer to similarities in how the viewers' brains responded to the movie, which does not mean that they had the same thoughts or feelings. Moreover, given the secondary nature of our study, we unfortunately cannot report data about viewers' level of comprehension.

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*Supplementary Table 1. Coded segments for content-based ISC analysis*

| | **Onset Second (TR)** | **Offset Second (TR)** | **Description** |
|---|---|---|---|
| Premise, Exposition | 28 (14) | 104 (52) | Clouds produce babies, storks deliver them. |
| Rising Action | 104 (52) | 246 (123) | Gus, the cloud, makes “dangerous” babies. The babies hurt Peck, the stork. |
| Climax, Fall out | 246 (123) | 290 (145) | Peck leaves for another cloud, Gus is very sad. |
| Resolution | 290 (145) | 328 (164) | Peck returns to Gus, carrying protective gear. They reunite. |