Engagement in video and audio narratives: contrasting self-report and physiological measures

Daniel C. Richardson1*, Nicole K. Griffin1, Lara Zaki1, Auburn Stephenson1, Jiachen Yan1, Thomas Curry2, Richard Noble2, John Hogan1, Jeremy I. Skipper1 & Joseph T. Devlin1

Stories play a fundamental role in human culture. They provide a mechanism for sharing cultural identity, imparting knowledge, revealing beliefs, reinforcing social bonds and providing entertainment that is central to all human societies. Here we investigated the extent to which the delivery medium of a story (audio or visual) affected self-reported and physiologically measured engagement with the narrative. Although participants self-reported greater involvement for watching video relative to listening to auditory scenes, stronger physiological responses were recorded for auditory stories. Sensors placed at their wrists showed higher and more variable heart rates, greater electrodermal activity, and even higher body temperatures. We interpret these findings as evidence that the stories were more cognitively and emotionally engaging at a physiological level when presented in an auditory format. This may be because listening to a story, rather than watching a video, is a more active process of co-creation, and that this imaginative process in the listener’s mind is detectable on the skin at their wrist.

Stories help us make sense of the world. Narratives provide links to traditions, legends, archetypes, myths, and symbols and help connect us to others by forming and stabilizing social bonds, by reinforcing and enhancing the group’s memory, and by providing shared entertainment. Our oldest narratives date back many thousands of years and pre-date the advent of writing. For the majority of human history, stories were synonymous with the oral tradition; audiences listened to a story teller imparting a tale. In modern cultures, stories are just as important but now are delivered in a variety of mediums including written books (both physical and digital), videos (TV and films), and as auditory narratives. Here we investigated the extent to which the medium of a story (audio or visual) affected one’s engagement with the narrative.

“Engagement” is construed very differently across the literature1–4. In some cases, it refers to cognitive operations such as attention, effort or agency when performing a task1,2 while in others it refers more generally to participation in activities3,4. In this paper, we operationalize engagement in two ways: self-reported engagement of a narrative experience and physiological engagement as an indirect measure of the mental processing that generated that experience.

A good story takes the listener on a journey, evoking cognitive and emotional responses such that the listener experiences the story through a process of mental simulation of the people, events, actions, places and emotions from the narrative, as if these were being experienced directly5–7. Indeed, there is evidence that narratives recreate a similar pattern of brain activity in the listener that was produced by the storyteller. Silbert et al.8 used functional magnetic resonance imaging (fMRI) to scan the brain of a volunteer speaking a 15-min personal story. Another set of volunteers then listened to this story while having their brains scanned. The authors identified the set of brain regions engaged by these tasks and found widespread coupling between activity in the speaker’s brain and that in the listeners’ brains. In other words, the act of listening to the narrative recreated the same basic pattern of brain activity as telling the story. This could mean that listeners share the same mental representations as the speaker9,10, but at a minimum it demonstrates that listening to the story produces similar neural processing, which may suggest it is similar to experiencing the speaker’s memory of the events. Moreover, activation was not limited to regions of the brain classically related to language, but also involved emotional, sensory and motor systems consistent with the notion that at some level, the listener actually experiences the story.

1Experimental Psychology, University College London, London, UK. 2Audible, London, UK. *email: dcr@eyethink.org
Historically, story-telling relied primarily on spoken language, and then more recently on written language, but in the modern era video has emerged as a major narrative tool as well. The main difference between these channels is the information they provide. Spoken words come in a single modality, namely audition, and have a very abstract relation to the content of the narrative. Consider a story that contains the sentence: “The was house ablaze.” A listener will correctly interpret this to mean that the house was on fire and possibly imagine what it might be like but the actual physical stimulus—in this case, changes in acoustic energy over time—is unrelated to the content being conveyed except through the interpretation of language. Video, on the other hand, is more closely related to the content. Seeing a video of a burning house, hearing the sounds of the fire—these are physical stimuli that directly convey the information without interpretation and without language. In other words, because of their different information content, these two channels require very different processing despite the fact that they can convey identical narrative content. Oral and written stories require a more active processing in the sense that the listener/reader reconstructs a personalized interpretation of the narrative. In contrast, watching video is a more passive process due to the fact that there is less scope for personal interpretation. Indeed, fajdelska et al. recently reviewed a wide field of evidence investigating the differences between narrative processing of spoken or written stories, and moving images. They concluded that, ‘verbal narrative generates more diverse responses than moving image narrative,’ and recommend that future research focuses on differences in neural mechanisms between the two. In this paper, we rise to that challenge, and predict that different levels of mental processing of auditory and video narratives will be reflected in different levels of physiological activity, specifically in heart rate, electrodermal activity and body temperature.

In its simplest form, increased heart rate is an indicator of increased effort and serves as an indirect measure of cognitive and emotional engagement. Changes in heart rate have been linked to increased information processing demands and/or greater mental effort. Linking heart rate to specific cognitive states, however, is not straightforward. Andreassi claimed that heart rates increase when people focus more on internal information and less on the external environment while Papillo and Shapiro argue that increased heart rate demonstrates cognitive elaboration, that is, the amplification of basic information processing activities such as encoding, attention, and emotional processing through discussion, meta-cognition or imagination. If narratives delivered in audiobook form require greater active mental simulation than watching videos, then we would expect to see increased heart rate for audio relative to video stories.

Electrodermal activity (EDA) is another physiological measure of engagement that is typically understood as an index of emotional arousal. One of the key emotional centres in the brain, the amygdala, stimulates the adrenal medulla, releasing the hormone adrenaline and enhancing autonomic nervous system activity. One consequence is the constriction of sweat glands in the dermis which increase skin conductance. EDA, therefore, provides an indirect method for measuring emotional arousal that can be used to evaluate whether stories presented in either the auditory or visual modality differentially engage emotional responses.

Changes in body surface temperature have recently been suggested to correlate with mood and social context. Since thermoregulation is biologically costly, IJzerman et al. argue that many social animals have evolved to share body warmth between themselves by directing blood towards the skin, and then huddling or engaging in skin-to-skin contact. Indeed, skin temperature on the hands increased by a fraction of a degree when participants watched film clips that produced positive, happy affect or engaged in positive social interactions and Kistler et al. found decreases in finger temperature in response to fear-inducing stimuli. By measuring body temperature at the wrist, we gain an independent physiological measure of potential differences between audiobook and video stories.

The question we asked here is whether a difference in the delivery channel would influence self report and physiological engagement with the narrative. Participants experienced the same set of eight scenes from fictional stories. For each story, participants either heard a passage from an audiobook, or saw a TV or movie adaptation of the same scene. For example, from the Game of Thrones book we chose the passage in which Arya witnesses her father’s beheading, and the same scene in the HBO adaptation.

Stimuli can be informationally equivalent if the same information can be extracted from each and computationally equivalent if it can be extracted with the same effort. Our stimuli are not equivalent in either of these senses. If a crowd scene is paused in the Game of Thrones scene, for example, a viewer could read off the colour of the clothing for every member in the shot. These are details that are not mentioned at all in the spoken narrative. But listeners to the audiobook are told, for example that Arya wondered why her sister looked happy. That information is either not present in the video at all, or has to be inferred from the actor’s emotions. Our claim therefore is not that the stimuli and informationally or computationally equivalent, but that they are narratively equivalent, in the sense that the same story elements are present in each. The ways that stories are realised in video versus spoken word—the different information in each format and the different demands that they place upon the reader or viewer engaged in the narrative—are precisely what that we want to contrast experimentally.

While watching and listening to the stories, biometric sensors were used to measure physiological engagement via heart rate, electrodermal activity and body temperature. All of these physiological signals are also affected by physical activity, and so we used accelerometers on the sensors to track and account for body motion. After each story, participants answered twelve questions of a narrative engagement scale that quantified their immersion in the narrative, their attention to the story, their closeness to the characters and their sense of presence in the narrative world.

**Method**

**Participants.** 109 participants were recruited from UCL’s subject pool and paid £10 for participation. Seven participants were excluded due to equipment failure or participant drop out. Of the 102 (41 M, 61 F) who completed the experiment, their ages ranged from 18 to 55 with an average age of 29 years old (SD = 10.5). The sen-
Thrones\(^2\)) and \(25\) Audiobooks were readings from the original texts, rather than acted out adapted audio plays, with 

Training was run on a PC, using the Gorilla online testing platform\(^3\) and participants wore headphones throughout.

wrist temperature and acceleration in 3 dimensions. They were led into a sound attenuated cubicle. The experi-

ence (e.g. "At times, the story was closer to me than the real world").

The nature of narrative 'engagement' is notoriously difficult to define across contexts and disciplines\(^3\). For 

our purposes, we operationalised participants' self-reported engagement in the stories by adapted the narrative 

engagement scale developed by Busselle and Bilandzic\(^2\), which is based on a mental models approach. This 

measure has the advantage of being validated across four dimensions of experiential engagement, which have 

been shown to be related to physiological measures\(^4\). The original scale referred to watching a program or film, 

and so we modified the language slightly to refer to stories that could be seen or heard. The scale is divided into 

four subscales with three questions relating to each: character engagement (e.g. "I understand why the main 

character thought and behaved as they did in the story"), narrative understanding (e.g. "I had hard time recog-

nizing the thread of the story"), attentional focus (e.g. "I had a hard time keeping my mind on the story"), and 

narrative presence (e.g. "At times, the story was closer to me than the real world").

Procedure. Participants were informed about the experiment and gave their consent to take part. They were 

fitted with an Empatica E4 wrist sensor, which captured their heart rate (HR), electrodermal activity (EDA), 

wrist temperature and acceleration in 3 dimensions. They were led into a sound attenuated cubicle. The experimen-

t was run on a PC, using the Gorilla online testing platform\(^3\) and participants wore headphones throughout.

They first completed a short demographic questionnaire and a survey asking about their consumption of movies, 

books and audiobooks.

Participants were presented with eight stories, in a block of four audio books and four videos. Across par-

participants we counterbalanced the order of these blocks, and which stories were presented as a video or audio 

book. In each trial, the participant first read a short synopsis of the plot and characters in the story so far, to give 

a context for the excerpt. They then watched the video onscreen or listened to the story while looking at a black 

screen. After presentation, participants reported whether or not they had experienced that excerpt before or not, 

and dragged a slider to indicate how familiar the characters were, and how familiar the scene was. Then they 

rated the 12 statements of the narrative engagement questionnaire, using a 7-point Likert scale that ranged from 

"strongly disagree" to "strongly agree." The experiment took approximately an hour to administer. On completion 

the participants were debriefed, thanked and paid for their time.

Data processing. Physiological data were aligned to stimulus and condition information and trimmed to 

trial durations using the Universal Time Coordinates that were recorded by the Empatica sensors and the Gorilla 

system. EDA measurements are typically susceptible to movement artifacts, and so we used the EDA Explorer 

algorithm\(^8\) to clean the EDA data using the acceleration data. The 3-dimensional acceleration vectors were then 

simplified into a single acceleration value that expressed movement magnitude in any direction.

All physiological measures were normalised for each participant. That is, the data were converted to a normal 

distribution by mean centring to zero and dividing by the standard deviation. This removed any baseline differ-

ences between individuals (e.g. their resting heart rates) and allowed us to focus on differences between story 

modalities within each participants' data. Across the duration of the experiment, participants heart rates and 

body temperatures decreased overall, and their skin conductance changed (see SI Fig. 1), also they shifted in their 

ratings between blocks. These slower changes, presumable due to sitting still for 50 min, are factored out of our 

analyses (see SI) by modelling trial and block order. Additionally, we ran the analyses below on the first block 

only of the experiment, and the same pattern of condition differences were found, albeit with reduced evidence 

strength. The data are available from the Open Science Framework at https://osf.io/u452g/.

Results

Participants reported that the videos were more engaging than the audio books by about 15% on average across 

our measures. Conversely, participants' physiological measures showed higher levels for audio books rather than 

videos. In terms of raw measures, their average heart rate was higher when they were listening to audio books by 

about two beats a minute; they had a greater range of heart rate by about 4 beats per minute; their skin conduct-

ance (EDA) was higher by 0.02 micro Siemens and they were roughly a third of a degree warmer in their body 

temperature (0.34 °C).
Figure 1 shows an example of the time-course of our physiological measures for the *Game of Thrones* story in two modalities. Since the audiobook and video had different durations, we have plotted our measures as a function of the proportion of the story time. The differences shown for this item were echoed across all stories (see Supplementary Materials).

Figure 2 presents the means and distributions for the participants’ self-report engagement ratings and normalized physiological measures, contrasting audio and video modalities. Beneath the observed data are probability distributions for the estimated differences between modalities. These estimates were derived from the posterior distributions given by Bayesian mixed models of our data. The Bayesian approach allowed us to directly quantify the effects of modality on behavioural and physiological measures and the strength of evidence in support of any differences, avoiding some of the problems associated with null hypothesis testing. In the Supplementary Information, we also report more traditional ANOVAs analyses, which produced the same pattern of conclusions.

For each of the dependent variables reported below, we used mixed models with fixed effects for story modality, which was varied within participants, and block order and stimuli order, which were varied between participants as counterbalancing measures. We used random effects for participants, story, and trial number, to model changes in measures during the course of the experimental hour. We used R (version 3.4.3) the rstanarm package to model the data, and the psycho package to interpret it. In our models, we employed weakly informative priors that were scaled following the standard rstanarm procedure.

From 4,000 simulations, we generated estimates of the posterior distributions of the model parameter coefficients, which quantify the strength of the evidence that each experimental condition influenced behaviour. Full details of our models, priors, and all parameter estimates are given in the SI.

Here we report estimates of the differences between audio and video modalities. The full probability distributions of these difference estimates are shown in the bottom row of Fig. 2, below the observed data. Median estimates for the differences are given in the text below. We quantify the strength of the evidence in support of these differences using the Maximum Probability of Effect (MPE). This is the probability that the effect is positive or negative (depending on the median’s direction). In other words, the MPE directly quantifies the probability that the experimental condition had an effect. In Fig. 2 we also show 95% credible intervals for these estimates in grey (in other words, where the evidence suggests that there is 95% chance that the differences fall).

**Reported engagement.** There was strong evidence that participants rated their engagement higher for videos rather than audiobooks. Summing the 3 questions for each subscale gave a value between 3 and 21. For their attention to the story, the median of the posterior distribution for the effect of the video condition was
3.62 points higher (MPE > 99.99%). For their engagement with the narrative, the median was 1.75 points higher (MPE > 99.99%). For their ratings of presence, the median was 1.95 points higher (MPE > 99.99%). For rated engagement with characters, there was a smaller but reliable difference of 0.35 points in favour of the videos (MPE = 98.23%). In other words, there was strong evidence that participants self-reported greater engagement for videos relative to audio stories for all measures of engagement.

Physiological measures. The physiological evidence consistently demonstrated stronger responses for the audio relative to the video condition. The median estimate of normalized mean heart rates was 0.20 higher for audiobooks (MPE > 99.99%). The median standard deviation of heart rates was also greater by 0.08 (MPE = 99.75%). The median of the estimated EDA readings was 0.28 higher for audio books (MPE > 99.99%), and participants had a median estimate of normalised wrist temperature that was 0.19 higher for audiobooks (MPE = 99.35%).

One possible explanation for the higher physiological responses may be that participants were more physically active when listening to audiobooks—that is, they could have been fidgeting more, consistent with their self-reported lower engagement. To assess this, we examined the acceleration data from the Empatica sensors. There was no strong evidence that participants moved more during audiobooks, with the median estimated...
Semantic ambiguity refers to the fact that most words in English have more than one meaning which makes them ambiguous. For example, in a sentence like “The woman made the toast with a new microphone,” the word “toast” is ambiguous—it could refer to cooked bread or a call to drink together. It is not until the word “microphone” is encountered that the meaning becomes clear. Although this appears to occur effortlessly, resolving ambiguity is a complex process involving multiple cognitive operations, supported by a set of brain regions including Broca’s area and posterior parts of the temporal lobe. There is, however, less ambiguity in the video equivalent, where the image of a woman speaking into a microphone is clear from the outset. Even if they are unaware of it, the listener is working harder to understand the story than a person viewing a video would. As a result, listening to a story will be more active and therefore more demanding process than watching videos.

A second potential confound between the modalities was the fact that on average, audio scenes were longer than the equivalent video clips by approximately 100 s. To avoid cumulative differences in effort over time, we compare mean scores. Even so, if there were an upward linear trend with time, this could potentially inflate the difference with the longer clips showing larger effects. The data from all eight stories are shown in Supplemental Fig. 1. To investigate whether the longer clips affected the results, we trimmed all the physiological data to the length of the shortest modality (usually the video clip) and re-analysed the results. For each trial, the location of the trimming was chosen at random, and so the shortened data were equally likely to contain portions of the start or end of the full recording. The median estimate of normalized mean heart rates was 0.17 higher for audiobooks (MPE = 99.98%). The median standard deviation of heart rates was also greater by 0.06 (MPE = 97.52%). The median of the estimated EDA readings was 0.28 higher for audio books (MPE = 99.95%), and participants’ wrist temperature had a median estimated increase of 0.19 (MPE = 99.56%). In other words, the pattern of findings remained the same when the clips were truncated at a random location to the same duration across modalities.

Familiarity. On a trial by trial basis, we computed how familiar the story and characters were to participants. Reported familiarity correlated positively and significantly with each of the four dimensions of reported engagement, but crucially, these correlations held equally for both audio and visual modalities (i.e. there was no statistical evidence that r values were significantly different between modalities by Zhou’s test). Reported familiarity did not correlate with any physiological responses, either for all items together, or for audio and video items separately. We concluded that while participants found familiar stories more engaging overall, this does not reveal anything about differences between audio and video narratives.

Discussion

The term ‘engagement’ has different levels of meaning. In one sense, engagement relates to the richness of the experience while in another, is related to the degree of mental processing that generates that experience. In the case of audio versus video narratives, we have found a case where those two senses diverge.

Participants reported higher levels of engagement while watching video scenes compared to listening to audio scenes. They attended more, showed greater narrative understanding and reported greater narrative presence when watching video clips, suggesting that they not only found video narratives easier to comprehend, but also immersed themselves more fully in the world created by the video narratives. In other words, people found the videos more engaging according to their self-report. Interestingly, their implicit physiological measures told a different story. On average, heart rates were higher and more variable, electrodermal activity was greater and temperatures were raised when listening to audio narratives than when watching video narratives. These findings suggest that listening to audio stories engaged greater cognitive and emotional processing than watching videos.

If increased heart rate is truly an indicator of increased effort, these results are consistent with the hypothesis that listening to a story is a more active process, and therefore more cognitively and emotionally engaging than viewing the same story. In essence, the listener mentally simulates the narrative more so than viewers of the narrative, who more passively process the visualization provided by the video’s director.

Of course, this is a relative difference: understanding the narrative of a film certainly engages a range of cognitive and emotional processes. A recent study illustrated this by measuring brain activity while volunteers listened to stories that were either visually vivid, action-based, or emotionally charged. All three story-types activated the temporal lobes and Broca’s area, as expected, but the interesting findings pertained to the differences between the stories. Specifically, visually vivid stories activated the occipito-parietal junction and the pre-cuneus, two regions associated with visuo-spatial processing. Action-based stories, in contrast, activated regions of premotor cortex while emotionally laden stories activated parts of the limbic system typically linked to affective responses, demonstrating that listening to stories engaged not only core “language regions” of the brain such as Broca’s area, but also recruited additional brain systems depending on the context. This is consistent with the notion that understanding a narrative involves mental simulation that retrieve the listener’s perceptual, motor, and affective knowledge through reactivation of the neural systems responsible for perception, action, and emotion.

Another fundamental difference between purely language-based stories and video is the presence of semantic ambiguity. Semantic ambiguity refers to the fact that most words in English have more than one meaning which means that listeners/readers are frequently resolving ambiguities, often without even noticing them. For example, in a sentence like “The woman made the toast with a new microphone,” the word “toast” is ambiguous—it could refer to cooked bread or a call to drink together. It is not until the word “microphone” is encountered that the meaning becomes clear. Although this appears to occur effortlessly, resolving ambiguity is a complex process involving multiple cognitive operations, supported by a set of brain regions including Broca’s area and posterior parts of the temporal lobe. There is, however, less ambiguity in the video equivalent, where the image of a woman speaking into a microphone is clear from the outset. Even if they are unaware of it, the listener is working harder to understand the story than a person viewing a video would. As a result, listening to a story will be a more active and therefore more demanding process than watching the video.

There was also strong evidence from the physiological data for greater emotional engagement with the audio relative to the video versions of the stories. We observed significantly higher electrodermal activity (EDA) and skin temperatures when participants listened to audio narratives compared to when they watched the same narratives as video. These results demonstrate that when listening to audio stories, participants experienced greater arousal than when watching video stories.
Physiological measures such as heart rate, EDA, and skin temperature are indirect indices of engagement. In each case the measure is a summary of autonomic nervous system activity which include additional factors beyond cognitive and emotional engagement (e.g. breathing, digestion, electrolyte concentrations, etc.—all of which relate to internal bodily states rather than external stimuli). Moreover, it is difficult to convincingly disentangle cognition from emotion for both practical and theoretical reasons. In practice, cognitive effort and emotional arousal have common effects on the autonomous nervous system that drive the physiological responses being measured here12–14,18,19. As a result, there is no way to disentangle the two based solely on heart rate or EDA measures. A more fundamental reason, however, is that emotions are simply not distinct from other forms of cognition—despite a widespread assumption to the contrary49,50, which is why we choose to interpret the current findings as evidence of “cognitive and emotional engagement.”

Of course, it is possible that these conclusions are specific to the particular narratives that we selected. Though they span genres, they are all cases of successful narratives, in the sense that people chose to record audio books across the time course of items (see SI Fig. 3). An intriguing open question is the degree to which our findings content, the pattern of differences we found between conditions are replicated very consistently across items, and so across the time course of items (see SI Fig. 3). An intriguing open question is the degree to which our findings are true of engagement in art forms that are non-linguistic (such as music versus music and dance), or stimuli that are linguistic but less narrative-driven, such as cooking instructions.

Conclusion

We found that participants perceived themselves to be more concentrated and engaged while watching video narratives, but their physiological responses revealed more cognitive and emotional engagement while listening to audio narratives. Why do they feel more engaged if their bodies say otherwise? We suggest that spoken narratives require the participant to be an actively engaged listener, whereas videos deliver rich stimulation to a more passive viewer. The pictures in the listener’s mind may not be as vivid and as detailed as those onscreen, and so auditory narratives are rated explicitly as less engaging; yet the imaginative generation of those images requires greater cognitive and emotional processing, and so they are physiologically more engaging.

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References

1. Beymer, P. N. et al. Examining relationships among choice, affect, and engagement in summer STEM programs. J. Youth Adolesc. 47(6), 1178–1191 (2018).
2. Ellis, G. D., Freeman, P. A. & Jiang, J. Measurement of deep structured experiences as a binary phenomenon. Ann. Leisure Res. 22(1), 119–126 (2019).
3. Finn, J. & Zimmer, K. Student engagement: what is it? Why does it matter? In Handbook of Research of Student Engagement (eds Christenson, S. L. et al.) 133–145 (Springer, New York, 2012).
4. Fredricks, J. A., Bohnert, A. M. & Burdette, K. Moving beyond attendance: lessons learned from assessing engagement in afterschool contexts. New Dir. Youth Dev. 2014(144), 45–58 (2014).
5. Barsalou, L. W. Perceptual symbol systems. Behav. Brain Sci. 22(4), 577–609 (1999) (Discussion 610–660).
6. Zwaan, R. A. Situation models: the mental leap into imagined worlds. Curr. Dir. Psychol. Sci. 8(1), 15–18 (1999).
7. Bergen, R. K. et al. Spatial and linguistic aspects of visual imagery in sentence comprehension. Cogn. Sci. 31(5), 733–764 (2007).
8. Silbert, L. J. et al. Coupled neural systems underlie the production and comprehension of naturalistic narrative speech. Proc. Natl. Acad. Sci. USA 111(43), E4687–E4696 (2014).
9. Chen, J. et al. Shared memories reveal shared structure in neural activity across individuals. Nat. Neurosci. 20(1), 115–125 (2017).
10. Zadbood, A. et al. How we transmit memories to other brains: constructing shared neural representations via communication. Cereb. Cortex 27(10), 4988–5000 (2017).
11. Iajdelka, E. et al. Picture this: a review of research relating to narrative processing by moving image versus language. Front. Psychol. 10, 1161 (2019).
12. Andreassi, J. L. Psychophysiology: Human Behaviour and Physiological Response 5th edn. (Lawrence Erlbaum Associates, Mahwah, NJ, 2007).
13. Potter, R. E. & Bolls, P. D. Psychophysiological Measurement and Meaning: Cognitive and Emotional Processing of Media (Routledge, New York, 2012).
14. Sukalla, F. et al. Embodiment of narrative engagement: connecting self-reported narrative engagement to psychophysiological measures. J. Media Psychol. 28(4), 175–186 (2016).
15. Papillo, J. E. & Shapiro, D. The cardiovascular system. In Psychophysiology: Physial, Social and Intermitial Elements (eds Cacioppo, J. T. & Tassinary, L. G.) 456–512 (Cambridge University Press, New York, 1990).
16. O’Donnell, A. M. & Dansereau, D. F. Scripted cooperation in student dyads: a method for analyzing and enhancing academic learning and performance. In Interaction in Cooperative Groups: The theoretical Anatomy of Group Learning (eds Herz-Lazarowitz, R. & Miller, N.) 120–144 (Cambridge University Press, New York, 1992).
17. Webb, N. Peer interaction and learning in small groups. Int. J. Educ. Res. 13, 21–39 (1989).
18. Critchley, H. D. Electrodermal responses: what happens in the brain. Neuroscience 98(2), 132–142 (2002).
19. Sequeira, H. et al. Electrical autonomic correlates of emotion. Int. J. Psychophysiol. 62(1), 50–56 (2009).
20. Ioannou, S., Gallese, V. & Merla, A. Thermal infrared imaging in psychophysiology: potentialities and limits. Psychophysiology 51(10), 951–963 (2014).
21. Izerman, H. et al. A theory of social thermoregulation in human primates. Front. Psychol. 6, 464 (2015).
22. Rimm-Kaufman, S. E. & Kagan, J. The psychological significance of changes in skin temperature. Motivation and Emotion 20(1), 63–78 (1996).
23. Hahn, A. C. et al. Hot or not? Thermal reactions to social context. Biol. Lett. 8, 864–867 (2012).
24. Kistler, A., Mariauzoulis, C. & von Berlepsch, K. Fingertip temperature as an indicator for sympathetic responses. Int. J. Psychophysiol. 29(1), 35–41 (1996).
25. Martin, G. B. R. A Song of Ice and Fire. A Game of Thrones (Harper Voyager, London, 1991).
26. Benioff, D. & Weiss, D. Games of Thrones (TV Series 2011) (HBO, London, 2015).
27. Baggett, P. Understanding visual and verbal messages. Adv. Psychol. 58, 101–124 (1989).
28. Schnotz, W. Toward an integrative view of text and picture comprehension: visualization effects on the construction of mental models. *Educ. Psychol. Rev.* 14(1), 101–120 (2002).
29. Busselle, R. & Bilandzic, H. Measuring narrative engagement. *Media Psychol.* 12(4), 321–347 (2009).
30. Austen, J. *Pride and Prejudice* (Wisehouse Classics, London, 1797).
31. Dickens, C. *Great Expectations* (Wordsworth Classics, London, 1860).
32. Hawkins, P. *The Girl on the Train* (Doubleday, London, 2015).
33. Brown, D. *The Da Vinci Code* (Transworld and Bantam Books, London, 2003).
34. Conan Doyle, A. *A Study in Scarlet* (Ward Lord & Co, London, 1887).
35. Harris, T. *The Silence of the Lambs* (St. Martins Press, London, 1988).
36. Golden, C. *Alien: River of Pain* (Titan Books, London, 2014).
37. Reschly, A. L. & Christenson, S. L. Jingle, jangle and conceptual haziness: Evolution and future directions of the engagement construct. In *Handbook of Research on Student Engagement, 2012* (eds Christenson, S. L. *et al.*) 133–145 (Springer, New York, 2012).
38. Anwyl-Irvine, A. *et al.* Gorilla in our midst: an online behavioural experiment builder. *bioRxiv* https://doi.org/10.1101/438242 (2018).
39. Taylor, S., *et al.* Automatic identification of artifacts in electrodermal activity data. In 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC) (2015).
40. Sorensen, T., Hohenstein, S. & Vasicth, S. Bayesian linear mixed models using Stan: a tutorial for psychologists, linguists, and cognitive scientists. *Quant. Methods Psychol.* 12(3), 175–200 (2016).
41. Kruschke, J. K. Bayesian data analysis. *Wiley Interdiscip. Rev. Cogn. Sci.* 1, 658–676 (2010).
42. Wagenmakers, E. *et al.* Why psychologists must change the way they analyze their data: the case of psi: comment on Bern (2011). *J. Pers. Soc. Psychol.* 100(3), 426–432 (2011).
43. Team, S.D., *et al.* *rstanarm: Bayesian applied regression modeling via Stan.* R package version 2.13.1. (2016).
44. Makowski, D. The psycho package: an efficient and publishing-oriented workflow for psychological science. *J. Open Source Softw.* 3, 470 (2018).
45. Chow, H. M. *et al.* Embodied comprehension of stories: interactions between language regions and modality-specific neural systems. *J. Cogn. Neurosci.* 26(2), 279–295 (2014).
46. Rodd, J. M., Gaskell, G. & Marslen-Wilson, W. Making sense of semantic ambiguity: semantic competition in lexical access. *J. Mem. Lang.* 46(2), 245–266 (2002).
47. Rodd, J. M., Davis, M. H. & Johnsrude, I. S. The neural mechanisms of speech comprehension: fMRI studies of semantic ambiguity. *Cereb. Cortex* 15(8), 1261–1269 (2005).
48. Zemplen, M. Z. *et al.* Semantic ambiguity processing in sentence context: evidence from event-related fMRI. *Neuroimage* 34(3), 1270–1279 (2007).
49. Duffy, E. The psychological significance of the concept of arousal or activation. *Psychol. Rev.* 64(5), 265–275 (1957).
50. Feldman Barret, L. *How Emotions Are Made: The Secret Life of the Brain* (Houghton Mifflin Harcourt, New York, 2016).

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**Author contributions**

Experiment was conceived and designed by J.T.D., J.H., T.C., R.N., J.S., and D.C.R.; data collection was performed by N.K.G., L.Z., A.S., and J.Y.; data analysis was performed by D.C.R. and J.T.D.; manuscript was written by J.T.D.

**Competing interests**

The authors declare no competing interests.

**Additional information**

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Correspondence and requests for materials should be addressed to D.C.R.

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