

# 1 Semantic reconstruction of continuous language from non-invasive brain recordings

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## 8 9 **Abstract**

10  
11 A brain-computer interface that decodes continuous language from non-invasive recordings  
12 would have many scientific and practical applications. Currently, however, decoders that  
13 reconstruct continuous language use invasive recordings from surgically implanted electrodes<sup>1-3</sup>,  
14 while decoders that use non-invasive recordings can only identify stimuli from among a small set  
15 of letters, words, or phrases<sup>4-7</sup>. Here we introduce a non-invasive decoder that reconstructs  
16 continuous natural language from cortical representations of semantic meaning<sup>8</sup> recorded using  
17 functional magnetic resonance imaging (fMRI). Given novel brain recordings, this decoder  
18 generates intelligible word sequences that recover the meaning of perceived speech, imagined  
19 speech, and even silent videos, demonstrating that a single language decoder can be applied to a  
20 range of semantic tasks. To study how language is represented across the brain, we tested the  
21 decoder on different cortical networks, and found that natural language can be separately  
22 decoded from multiple cortical networks in each hemisphere. As brain-computer interfaces  
23 should respect mental privacy<sup>9</sup>, we tested whether successful decoding requires subject  
24 cooperation, and found that subject cooperation is required both to train and to apply the  
25 decoder. Our study demonstrates that continuous language can be decoded from non-invasive  
26 brain recordings, enabling future multipurpose brain-computer interfaces.

## 27 28 **Main Text**

29  
30 Previous brain-computer interfaces have demonstrated that speech articulation<sup>1</sup> and other motor  
31 signals can be decoded from intracranial recordings to restore communication to people who

32 have lost the ability to speak<sup>2,3</sup>. While effective, these decoders require invasive neurosurgery,  
33 making them unsuitable for most other uses. Non-invasive language decoders could be more  
34 widely adopted, and may eventually help all people interact with technological devices through  
35 thought<sup>4-7</sup>.

36  
37 We introduce a decoder that takes non-invasive fMRI brain recordings and reconstructs arbitrary  
38 stimuli that the subject is hearing or imagining in continuous natural language. To accomplish  
39 this we needed to overcome one major obstacle: the low temporal resolution of fMRI. While  
40 fMRI has excellent spatial specificity, the blood-oxygen-level-dependent (BOLD) signal that it  
41 measures is notoriously slow—an impulse of neural activity causes BOLD to rise and fall over  
42 approximately 10 seconds<sup>10</sup>. For naturally spoken English (over 2 words per second), this means  
43 that each brain image can be affected by over 20 words. Decoding continuous language thus  
44 requires solving an ill-posed inverse problem, as there are many more words to decode than brain  
45 images. Our decoder accomplishes this by guessing candidate word sequences, scoring the  
46 likelihood that each candidate evoked the recorded brain responses, and then selecting the best  
47 candidate.

48  
49 To compare word sequences to a subject's brain responses, we trained an encoding model<sup>8</sup> that  
50 predicts how that subject's brain responds to phrases in natural language. This model can score  
51 the likelihood that the subject is hearing or imagining a candidate sequence by measuring how  
52 well the recorded brain responses match the predicted brain responses<sup>11,12</sup>. To learn how the  
53 brain responds to a wide range of phrases, we recorded responses while the subject listened to  
54 sixteen hours of naturally spoken narrative stories, yielding over five times more data than the  
55 typical language fMRI experiment. We trained an encoding model on this dataset by extracting  
56 semantic features that capture the meaning of stimulus phrases<sup>13-17</sup>, and then using linear  
57 regression to model how the semantic features influence brain responses (Fig. 1a). Given any  
58 word sequence, this encoding model predicts how the subject's brain would respond.

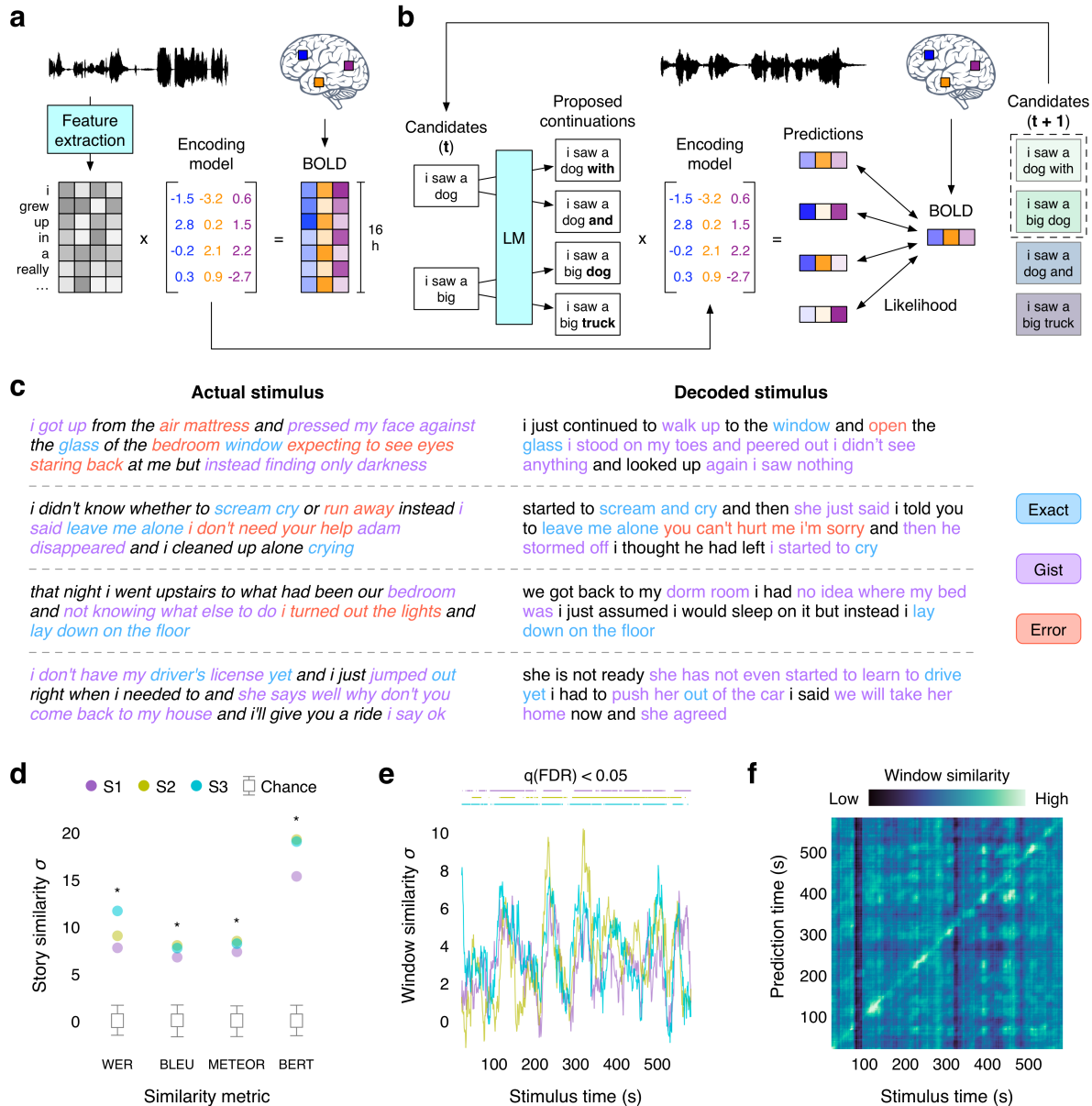
59  
60 In theory, we could identify the most likely stimulus that the subject is hearing or imagining by  
61 comparing the recorded brain responses to encoding model predictions for every possible word  
62 sequence<sup>11,12</sup>. However, the number of possible word sequences is far too large for this approach

63 to be practical, and the vast majority of those sequences do not resemble natural language. To  
64 restrict the candidate sequences to well-formed English, we used a generative neural network  
65 language model<sup>18</sup> that was trained on a large dataset of natural English word sequences. Given  
66 any word sequence, this language model predicts the words that could come next.

67  
68 Yet even with the constraints imposed by the language model, it is computationally infeasible to  
69 generate and score all candidate sequences. To efficiently search the space of word sequences,  
70 we used a beam search algorithm<sup>19</sup> that generates candidate sequences word by word. In beam  
71 search, the decoder maintains a beam containing the  $k$  most likely candidate sequences at any  
72 given time. When new words are detected based on brain activity in auditory and speech regions  
73 (see Methods), the language model generates continuations for each candidate sequence in the  
74 beam. The encoding model then scores the likelihood that each continuation evoked the recorded  
75 brain responses, and the  $k$  most likely continuations are retained in the beam for the next  
76 timestep (Fig. 1b). This process continually approximates the stimulus that the subject is hearing  
77 or imagining across an arbitrary amount of time.

78  
79 We trained decoders for three subjects and evaluated each subject's decoder on separate, single-  
80 trial brain responses that were recorded while that subject listened to novel test stories that were  
81 not used for model training. Since our decoder represents language using semantic features rather  
82 than motor or acoustic features, the decoder predictions should capture the meaning of the  
83 stimuli. Results show that the decoded word sequences captured not only the meaning of the  
84 stimuli, but often even recovered exact words and phrases (Fig. 1c; Supplementary Table 1). To  
85 quantify decoding performance, we compared decoded and actual word sequences for one test  
86 story (1,800 words) using several language similarity metrics (see Methods). Standard metrics  
87 like word error rate (WER), BLEU, and METEOR measure the number of words shared by two  
88 sequences. However, because different words can convey the same meaning—for instance “we  
89 were busy” and “we had a lot of work”—we also used BERTScore, a newer method which uses  
90 machine learning to quantify whether two sequences share a meaning. Story decoding  
91 performance was significantly higher than expected by chance under each metric but particularly  
92 BERTScore ( $q(\text{FDR}) < 0.05$ , one-sided nonparametric test; Fig. 1d). Most time-points in the  
93 story (72-82%) had a significantly higher BERTScore than expected by chance (Fig. 1e) and

94 could be identified from other time-points (mean percentile rank = 0.85-0.90) based on  
 95 BERTScore similarities between the decoded and actual words (Fig. 1f; Extended Data Fig. 1a).  
 96



97

98

99 **Fig. 1. Language decoder.** (a) BOLD fMRI responses were recorded while three subjects listened to 16 h of  
 100 narrative stories. An encoding model was estimated for each subject to predict brain responses from semantic  
 101 features of stimulus words. (b) To reconstruct language from novel brain recordings, the decoder maintains a set of  
 102 candidate word sequences. When new words are detected, a language model (LM) proposes continuations for each  
 103 sequence and the encoding model scores the likelihood of the recorded brain responses under each continuation. The  
 104 most likely continuations are retained. (c) Decoders were evaluated on single-trial brain responses recorded while

105 subjects listened to test stories that were not used for model training. Segments from four test stories are shown  
106 alongside decoder predictions for one subject. The decoder exactly reproduces some words and phrases, and  
107 captures the gist of many more. **(d)** Decoder predictions for a test story were significantly more similar to the actual  
108 stimulus words than expected by chance under a range of language similarity metrics (\* indicates  $q(\text{FDR}) < 0.05$  for  
109 all subjects, one-sided nonparametric test). To compare across metrics, results are shown as standard deviations  
110 away from the mean of the null distribution (see Methods). Boxes indicate the interquartile range of the null  
111 distribution; whiskers indicate the 5th and 95th percentiles. **(e)** For most time points, decoding scores were  
112 significantly higher than expected by chance ( $q(\text{FDR}) < 0.05$ , one-sided nonparametric test) under the BERTScore  
113 metric. **(f)** Identification accuracy for one subject. The brightness at  $(i, j)$  reflects the similarity between the  $i$ th  
114 second of the prediction and the  $j$ th second of the actual stimulus. Identification accuracy was significantly higher  
115 than expected by chance ( $p < 0.05$ , one-sided permutation test).

116

## 117 **Decoding across cortical networks**

118

119 The decoding results shown in Figure 1 used responses from many different cortical regions to  
120 achieve good performance. This builds upon earlier reports that most parts of cortex contain  
121 some representations of language meaning<sup>8,20</sup>. However, it is unclear which cortical networks  
122 represent language in sufficient detail to decode complete word sequences<sup>6</sup>, and whether  
123 different networks—or hemispheres—play complementary or redundant roles in language  
124 processing<sup>21,22</sup>. To answer these questions, we partitioned brain data into three cortical  
125 networks—the classical language network<sup>23</sup>, the parietal-temporal-occipital association  
126 network<sup>20</sup>, and the prefrontal network—and separately decoded from each network in each  
127 hemisphere (Fig. 2a; Extended Data Fig. 1b).

128

129 Decoder predictions from each network in each hemisphere were significantly more similar to  
130 the actual stimulus than expected by chance ( $q(\text{FDR}) < 0.05$ , one-sided nonparametric test; Fig.  
131 2b). Notably, we successfully decoded continuous language from association and prefrontal  
132 networks without using any information from the classical language network except to detect  
133 when new words occurred. These results underscore the role of bilateral domain-general  
134 semantic regions in representing natural language<sup>8,24</sup>.

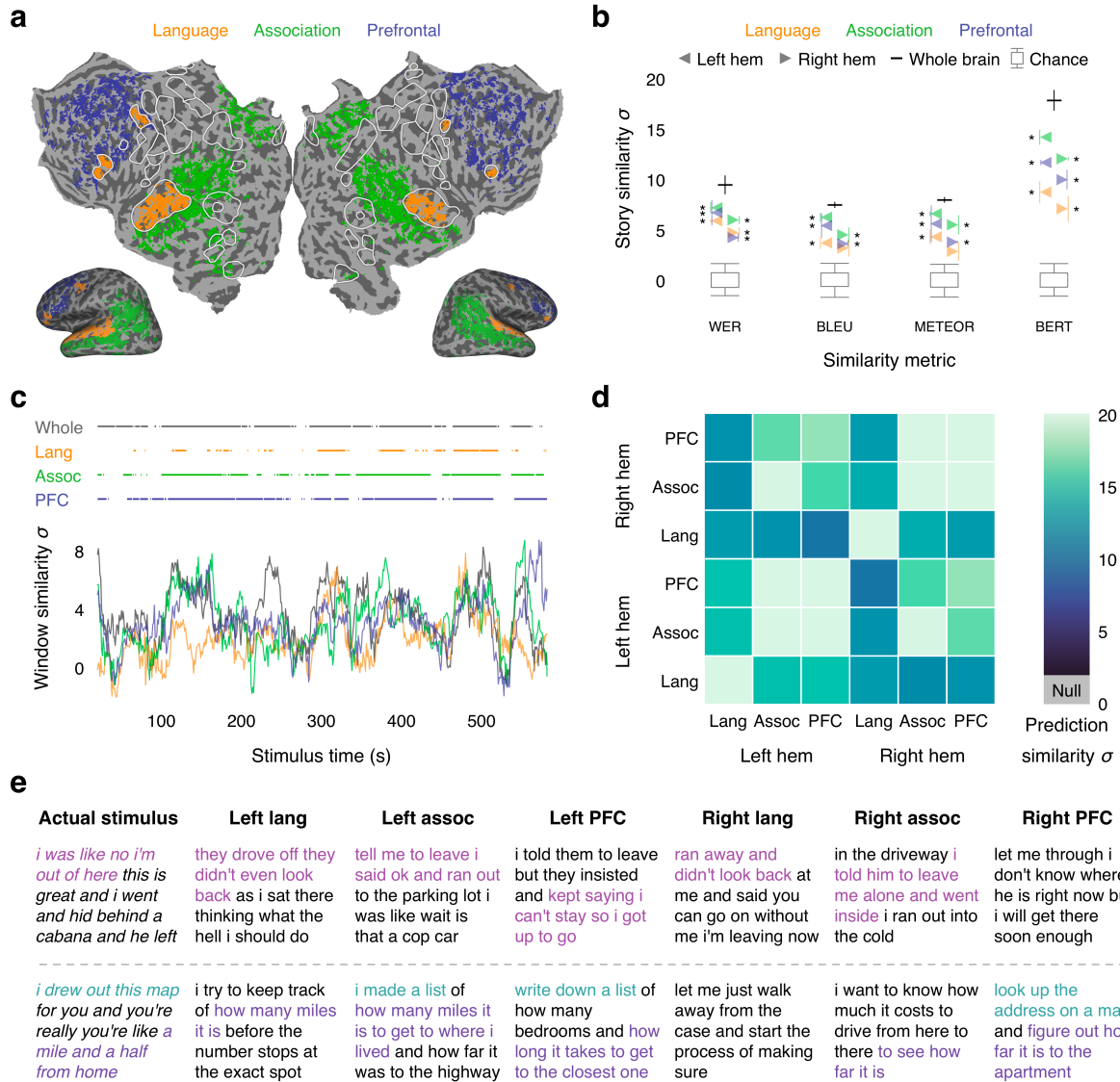
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136 One possible explanation for the successful decoding from multiple networks is that these  
137 networks encode complementary representations—such as different semantic categories—in a

138 modular organization. If this were the case, different parts of the stimulus may be decodable  
139 from each individual network, but the full stimulus should only be decodable from the whole  
140 brain. Alternatively, the different networks might encode redundant representations. If this were  
141 the case, the full stimulus may be separately decodable from each individual network.

142  
143 To differentiate these possibilities, we first computed the time-course of decoding performance  
144 for each network, and found that most time-points that were significantly decoded from the  
145 whole brain could also be decoded from association (77-83%) and prefrontal (54-82%) networks  
146 (Fig. 2c; Extended Data Fig. 1c). We then compared decoder predictions across networks and  
147 hemispheres, and found that the similarity between each pair of predictions was significantly  
148 higher than expected by chance ( $q(\text{FDR}) < 0.05$ , two-sided nonparametric test; Fig. 2d). This  
149 demonstrates that each of these cortical networks represents a substantial amount of redundant  
150 information (Fig. 2e), and suggests that future brain-computer interfaces could attain good  
151 performance even while selectively recording from brain regions that are most accessible or  
152 intact.

153



154

155

156 **Fig. 2. Decoding across cortical networks.** (a) Cortical networks for one subject. Brain data used for decoding

157 (colored regions) were partitioned into the classical language network, the parietal-temporal-occipital association

158 network, and the prefrontal network (PFC). (b) Decoder predictions from each network in each hemisphere were

159 significantly more similar to the actual stimulus words than expected by chance under most metrics (\* indicates

160  $q(\text{FDR}) < 0.05$  for all subjects, one-sided nonparametric test). Error bars indicate standard error of the mean ( $n = 3$

161 subjects). Boxes indicate the interquartile range of the null distribution; whiskers indicate the 5th and 95th

162 percentiles. (c) Decoding performance time-course from each network for one subject. Horizontal lines indicate

163 when decoding performance was significantly higher than expected by chance under the BERTScore metric

164 ( $q(\text{FDR}) < 0.05$ , one-sided nonparametric test). Most time-points that were significantly decoded from the whole

165 brain were also significantly decoded from association and prefrontal networks. (d) Decoder predictions were

166 compared across networks and hemispheres. Each pair of predictions were more similar than expected by chance

167 ( $q(\text{FDR}) < 0.05$ , two-sided nonparametric test). (e) Segments from a test story are shown alongside decoder  
168 predictions from each network in each hemisphere for one subject. Colors indicate corresponding phrases. These  
169 results demonstrate that cortical networks contain redundant representations of natural language.

170

## 171 **Decoder applications and privacy implications**

172

173 To demonstrate the wide range of potential applications for our decoder, we trained a single  
174 semantic language decoder for each subject using brain responses during story perception, and  
175 then applied it on brain responses during other tasks.

176

### 177 *Imagined speech decoding*

178

179 A key task for brain-computer interfaces is decoding covert speech that a subject imagines in the  
180 absence of external stimuli<sup>3</sup>. To test whether our language decoder can be used to decode covert  
181 speech, subjects imagined telling five one-minute stories while being recorded with fMRI, and  
182 separately told the same stories outside of the scanner to provide reference transcripts. Given  
183 fMRI recordings for each pair of stories, we correctly identified which recording corresponded to  
184 which story by comparing the decoder predictions to the reference transcripts (100% pairwise  
185 identification accuracy; Fig. 3a). Across stories, decoder predictions were significantly more  
186 similar to their reference transcripts than expected by chance ( $p < 0.05$ , one-sided nonparametric  
187 test). Qualitative analysis shows that the decoder can recover the meaning of imagined stimuli  
188 (Fig. 3b; Supplementary Table 2).

189

### 190 *Cross-modal decoding*

191

192 Semantic representations are shared between language and a range of perceptual and conceptual  
193 processes<sup>20,25,26</sup>, suggesting that, unlike previous language decoders that used mainly motor  
194 signals<sup>1,2</sup>, our semantic language decoder may be able to reconstruct language descriptions from  
195 brain responses to non-linguistic tasks. To test this, subjects watched four short films without  
196 sound while being recorded with fMRI, and the recorded responses were decoded using the  
197 semantic language decoder. We compared the decoded word sequences to audio descriptions of  
198 the films for the visually impaired (see Methods), and found that they were significantly more



199 similar than expected by chance ( $q(\text{FDR}) < 0.05$ , one-sided nonparametric test). Qualitatively,  
200 the decoded sequences accurately described events from the films (Fig. 3c; Supplementary Table  
201 3). This suggests that a single semantic decoder trained during story perception could be used to  
202 decode a range of semantic tasks.

203

#### 204 *Attention decoding*

205

206 Since semantic representations are modulated by attention<sup>27</sup>, our decoder should selectively  
207 reconstruct attended stimuli<sup>28,29</sup>. Beyond improving decoding performance in complex and noisy  
208 environments, this could enable our decoder to monitor attention levels and notify subjects when  
209 they start to get distracted. To test this, subjects listened to two repeats of a multi-speaker  
210 stimulus that was constructed by temporally overlaying a pair of stories told by female and male  
211 speakers, while attending to a different speaker for each repeat. Decoder predictions were  
212 significantly more similar to the attended story than to the unattended story ( $q(\text{FDR}) < 0.05$   
213 across subjects, one-sided paired  $t$ -test), demonstrating that the language decoder selectively  
214 reconstructs attended stimuli (Fig. 3d).

215

#### 216 *Privacy implications*

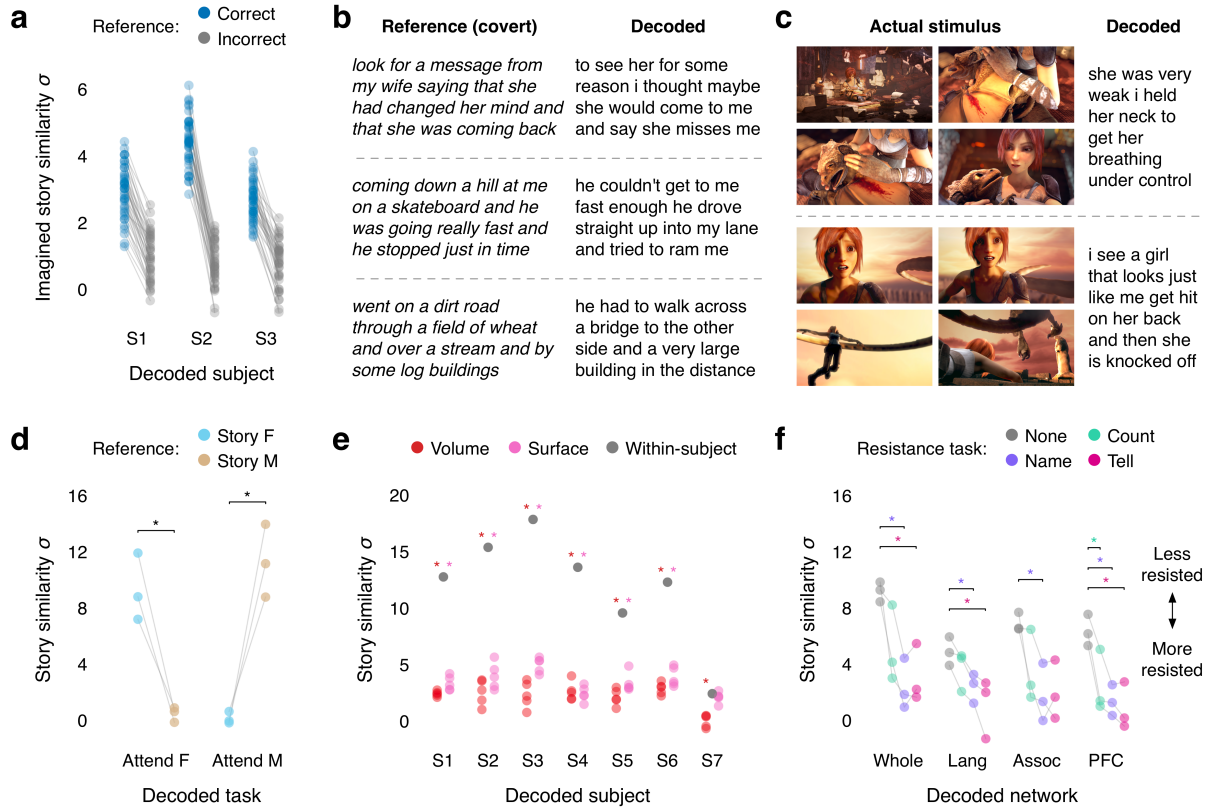
217

218 An important ethical consideration for semantic decoding is its potential to compromise mental  
219 privacy<sup>9</sup>. To test if decoders can be trained without a person's cooperation, we attempted to  
220 decode perceived speech from each subject using decoders trained on data from other subjects.  
221 For this analysis, we collected data from seven subjects as they listened to five hours of narrative  
222 stories. These data were anatomically aligned across subjects using volumetric and surface-based  
223 methods (see Methods). Decoders trained on cross-subject data performed barely above chance,  
224 and significantly worse than decoders trained on within-subject data ( $q(\text{FDR}) < 0.05$ , two-sided  
225  $t$ -test). This suggests that subject cooperation remains necessary for decoder training (Fig. 3e;  
226 Supplementary Table 4).

227

228 To test if a decoder trained with a person's cooperation can later be consciously resisted, subjects  
229 performed three covert cognitive tasks—calculation (“count by sevens”), semantic memory

230 (“name and imagine animals”), and imagined speech (“tell a different story”)—while listening to  
 231 segments from a narrative story. We found that performing the semantic memory task  
 232 significantly lowered decoding performance relative to a passive listening baseline for each  
 233 cortical network ( $q(\text{FDR}) < 0.05$  across subjects, one-sided paired  $t$ -test), demonstrating that  
 234 semantic decoding can be consciously resisted (Fig. 3f).  
 235



236

237

238 **Fig. 3. Decoder applications and privacy implications.** (a) To test whether the language decoder can transfer to  
 239 imagined speech, subjects imagined telling five 1-minute test stories twice. Single-trial brain responses were  
 240 decoded and compared to reference transcripts that were separately recorded from the same subjects. For every pair  
 241 of stories, the correct pairing of predictions and transcripts (prediction 1 with transcript 1, prediction 2 with  
 242 transcript 2) had higher similarity scores than the incorrect pairing (prediction 1 with transcript 2, prediction 2 with  
 243 transcript 1). (b) Reference transcripts are shown alongside decoder predictions for three imagined stories for one  
 244 subject. (c) To test whether the language decoder can transfer to another modality, subjects watched four silent short  
 245 films. Single-trial brain responses were decoded using the language decoder. Decoder predictions were significantly  
 246 related to the films ( $q(\text{FDR}) < 0.05$ , one-sided nonparametric test), and often accurately described film events.  
 247 Frames from two scenes are shown alongside decoder predictions for one subject. (d) To test whether the decoder is  
 248 modulated by attention, subjects listened to a multi-speaker stimulus that overlays stories told by a female and a

249 male speaker while attending to one or the other. Decoder predictions were significantly more similar to the attended  
250 story than to the unattended story (\* indicates  $q(\text{FDR}) < 0.05$  across  $n = 3$  subjects, one-sided paired  $t$ -test;  $t(2) =$   
251  $6.15$  for the female speaker,  $t(2) = 6.45$  for the male speaker). Markers indicate individual subjects. (e) To test  
252 whether decoding can succeed without training data from a particular subject, decoders were trained on brain  
253 responses from 5 sets of other subjects (indicated by markers) aligned using volumetric and surface-based methods.  
254 Cross-subject decoders performed substantially worse than within-subject decoders (\* indicates  $q(\text{FDR}) < 0.05$ , two-  
255 sided  $t$ -test), and barely above chance, suggesting that within-subject training data is critical. (f) To test whether  
256 decoding can be consciously resisted, subjects performed three resistance strategies: counting, naming animals, and  
257 telling a different story. Decoding performance under each condition was compared to a passive listening condition.  
258 Naming animals significantly lowered decoding performance in each cortical network (\* indicates  $q(\text{FDR}) < 0.05$   
259 across  $n = 3$  subjects, one-sided paired  $t$ -test;  $t(2) = 6.95$  for the whole brain,  $t(2) = 4.93$  for the language network,  
260  $t(2) = 3.89$  for the association network,  $t(2) = 151.20$  for the prefrontal network), demonstrating that decoding can be  
261 resisted. Markers indicate individual subjects. For all results, decoding scores depend on the length of the stimuli, so  
262 decoding scores are not comparable across different experiments (perceived speech, imagined speech, perceived  
263 movie, multi-speaker, decoder resistance).

264

## 265 **Sources of decoding error**

266

267 To identify potential avenues for improvement, we assessed whether decoding error during story  
268 perception reflects random noise in the brain recordings, model misspecification, or both (Fig.  
269 4a).

270

271 BOLD fMRI recordings typically have a low signal-to-noise ratio (SNR). During model  
272 estimation, the effects of noise in the training data can be reduced by increasing the size of the  
273 dataset. To evaluate if decoding performance is limited by the size of our training dataset, we  
274 trained decoders using different amounts of data. While decoding performance increased with  
275 the amount of training data, most of the improvement occurred by the seventh scanning  
276 session—or 7.5 hours—suggesting that simply collecting more data may not substantially  
277 improve decoding performance (Fig. 4b).

278

279 Low SNR in the test data may also limit the amount of information that can be decoded. To  
280 evaluate whether future improvements to single-trial fMRI SNR might improve decoding  
281 performance, we artificially increased SNR by averaging brain responses collected during  
282 different repeats of the test story. Decoding performance slightly increased with the number of

283 averaged responses (Fig. 4c), suggesting that some component of the decoding error reflects  
284 noise in the test data.

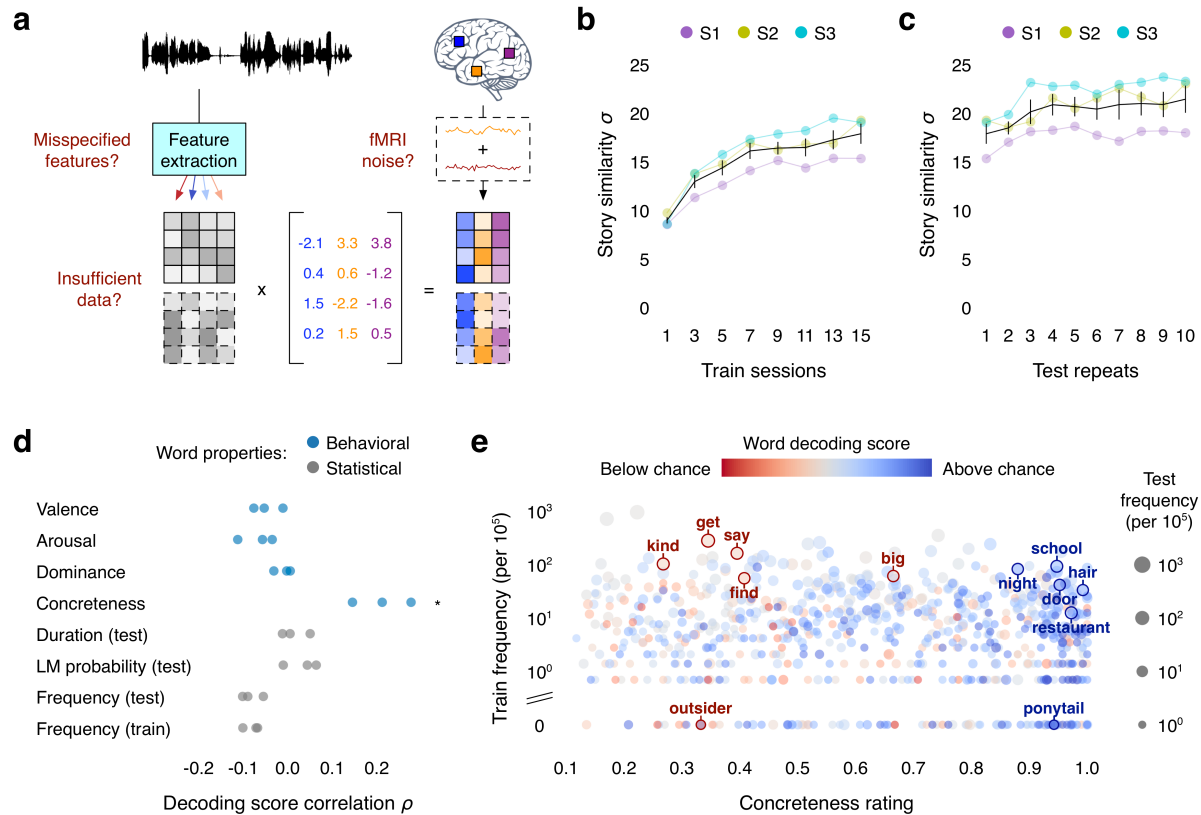
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286 Finally, to evaluate if decoding performance is limited by model misspecification—such as using  
287 suboptimal features to represent language stimuli—we tested whether the decoding error follows  
288 systematic patterns. We scored how well each individual word was decoded across six test  
289 stories (see Methods) and compared the scores to behavioral word ratings and dataset statistics.  
290 If the decoding error were solely caused by noise in the test data, all words should be equally  
291 affected. However, we found that decoding performance was significantly correlated with  
292 behavioral ratings of word concreteness (rank correlation  $\rho = 0.15-0.28$ ,  $q(\text{FDR}) < 0.05$ ),  
293 suggesting that the decoder is worse at recovering words with certain semantic properties (Fig.  
294 4d). Notably, decoding performance was not significantly correlated with word frequency in the  
295 training stimuli, suggesting that model misspecification is not primarily caused by noise in the  
296 training data (Fig. 4e).

297

298 Our results indicate that model misspecification is a major source of decoding error separate  
299 from random noise in the training and test data. We expect computational advances—such as the  
300 development of better models for extracting semantic features—to substantially reduce model  
301 misspecification and improve decoding performance.

302



**Fig. 4. Sources of decoding error.** (a) Potential factors limiting decoding performance. (b) To test if decoding performance is limited by the size of the training dataset, decoders were trained on different amounts of data. Decoding performance increased with the amount of training data collected from each subject but plateaued after 7 scanning sessions (7.5 h) and did not substantially increase up to 15 sessions (16 h). (c) To test if decoding performance is limited by noise in the test data, the signal-to-noise ratio of the test responses was artificially raised by averaging across repeats of the test story. Decoding performance slightly increased with the number of averaged responses. (d) To test if decoding performance is limited by model misspecification, word-level decoding scores were compared to behavioral ratings and dataset statistics (\* indicates  $q(\text{FDR}) < 0.05$  for all subjects, two-sided permutation test). Markers indicate individual subjects. (e) Decoding performance was significantly correlated with word concreteness—suggesting that model misspecification contributes to decoding error—but not word frequency in the training stimuli—suggesting that model misspecification is not caused by noise in the training data. For all results, black lines indicate the mean across subjects and error bars indicate standard error of the mean ( $n = 3$ ).

## Discussion

This study demonstrates that the meaning of perceived and imagined stimuli can be decoded from BOLD fMRI recordings into continuous language, marking an important step for non-

322 invasive brain-computer interfaces. While existing invasive methods decode from motor  
323 representations of articulator and hand motion<sup>1-3</sup>, our non-invasive method decodes directly from  
324 semantic representations of language meaning. Our analyses also suggest that semantic decoders  
325 trained during story perception can be used to decode other semantic tasks, which may enable  
326 augmentative applications such as brain-computer interfaces that transcribe visual experience or  
327 translate covert speech into different languages.

328  
329 While our decoder successfully reconstructs the meaning of language stimuli, it often fails to  
330 recover exact words (WER 0.92-0.94). This high WER for novel stimuli is comparable to out-of-  
331 set performance for previous invasive decoders<sup>30</sup>, indicating that this loss of specificity is not  
332 unique to non-invasive decoding. In our decoder, loss of specificity may occur because different  
333 word sequences with similar meanings can evoke similar semantic representations. Future  
334 decoders may benefit from modeling language stimuli using a combination of semantic features  
335 and lower level features such as phonemes or acoustics.

336  
337 One other important factor that may improve decoding performance is subject feedback.  
338 Previous invasive studies have employed a closed-loop decoding paradigm, where decoder  
339 predictions are shown to the subject in real time<sup>2,3</sup>. This feedback allows the subject to adapt to  
340 the decoder, providing them more control over decoder output<sup>31</sup>. While fMRI has lower temporal  
341 resolution than invasive methods, closed-loop decoding may still provide many benefits for  
342 imagined speech decoding.

343  
344 Finally, our privacy analysis suggests that subject cooperation is currently required both to train  
345 and use the decoder. However, future developments might enable decoders to bypass these  
346 requirements. Moreover, even if decoder predictions are inaccurate without subject cooperation,  
347 they could be intentionally misinterpreted for malicious purposes. For these and other unforeseen  
348 reasons, it is critical to raise awareness of the risks of brain decoding technology and enact  
349 policies that protect each person's mental privacy.

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417 **Methods**

418

419 **Subjects**

420

421 Data were collected from three female subjects and four male subjects: S1 (female, age 26 at  
422 time of most recent scan), S2 (male, age 36), S3 (male, age 23), S4 (female, age 23), S5 (female,  
423 age 23), S6 (male, age 25), and S7 (male, age 24). Data from S1, S2, and S3 were used for the  
424 main decoding analyses. Data from all subjects were used to estimate cross-subject decoders for  
425 a privacy analysis (Fig. 3e). All subjects were healthy and had normal hearing, and normal or  
426 corrected-to-normal vision. The experimental protocol was approved by the Institutional Review  
427 Board at the University of Texas at Austin. Written informed consent was obtained from all  
428 subjects. To stabilize head motion, subjects wore a personalized head case that precisely fit the  
429 shape of each subject's head.

430

431 **MRI data collection**

432

433 MRI data were collected on a 3T Siemens Skyra scanner at the UT Austin Biomedical Imaging  
434 Center using a 64-channel Siemens volume coil. Functional scans were collected using gradient  
435 echo EPI with repetition time (TR) = 2.00 s, echo time (TE) = 30.8 ms, flip angle = 71°, multi-  
436 band factor (simultaneous multi-slice) = 2, voxel size = 2.6mm x 2.6mm x 2.6mm (slice  
437 thickness = 2.6mm), matrix size = (84, 84), and field of view = 220 mm.

438

439 Anatomical data for all subjects except S2 were collected using a T1-weighted multi-echo MP-  
440 RAGE sequence on the same 3T scanner with voxel size = 1mm x 1mm x 1mm following the  
441 Freesurfer morphometry protocol. Anatomical data for subject S2 were collected on a 3T  
442 Siemens TIM Trio scanner at the UC Berkeley Brain Imaging Center with a 32-channel Siemens  
443 volume coil using the same sequence.

444

445 **Cortical networks**

446

447 Whole brain MRI data were partitioned into 3 cortical networks: the classical language network,  
448 the parietal-temporal-occipital association network, and the prefrontal network.

449

450 The classical language network was separately localized in each subject using an auditory  
451 localizer and a motor localizer. Auditory localizer data were collected in one 10 min scan. The  
452 subject listened to 10 repeats of a 1 min auditory stimulus containing 20 s of music (Arcade  
453 Fire), speech (Ira Glass, *This American Life*), and natural sound (a babbling brook). To determine  
454 whether a voxel was responsive to auditory stimulus, the repeatability of the voxel response  
455 across the 10 repeats was calculated using an  $F$  statistic. This map was used to define the  
456 auditory cortex (AC). Motor localizer data were collected in two identical 10 min scans. The  
457 subject was cued to perform six different tasks (“hand”, “foot”, “mouth”, “speak”, “saccade”,  
458 and “rest”) in a random order in 20 s blocks. For the “speak” cue, subjects were instructed to  
459 self-generate a narrative without vocalization. The weight map for the “speak” cue was used to  
460 define Broca’s area and the superior ventral premotor (sPMv) speech area.

461

462 The parietal-temporal-occipital association network and the prefrontal network were localized in  
463 each subject using Freesurfer anatomical ROIs. Voxels identified as part of the classical  
464 language network (AC, Broca’s area, and sPMv) were excluded from the parietal-temporal-  
465 occipital association and prefrontal networks.

466

## 467 **Experimental tasks**

468

469 The model training dataset consisted of 82 5-15 min stories taken from *The Moth Radio Hour*  
470 and *Modern Love*. In each story, a single speaker tells an autobiographical narrative. Each story  
471 was played during a separate fMRI scan with a buffer of 10 s of silence before and after the  
472 story. These data were collected during 16 scanning sessions, with the first session consisting of  
473 the anatomical scan and localizers, and the 15 subsequent sessions each consisting of 5 or 6  
474 stories. All 15 story sessions were collected for subjects S1, S2, and S3. The first 5 story sessions  
475 were collected for the remaining subjects.

476

477 Stories were played over Sensimetrics S14 in-ear piezoelectric headphones. The audio for each  
478 stimulus was filtered to correct for frequency response and phase errors induced by the  
479 headphones using calibration data provided by Sensimetrics and custom Python code  
480 ([https://github.com/alexhuth/sensimetrics\\_filter](https://github.com/alexhuth/sensimetrics_filter)). All stimuli were played at 44.1 kHz using the  
481 pygame library in Python.

482

483 Each story was manually transcribed by one listener. Certain sounds (for example, laughter and  
484 breathing) were also marked to improve the accuracy of the automated alignment. The audio of  
485 each story was then downsampled to 11kHz and the Penn Phonetics Lab Forced Aligner  
486 (P2FA)<sup>32</sup> was used to automatically align the audio to the transcript. After automatic alignment  
487 was complete, Praat<sup>33</sup> was used to check and correct each aligned transcript manually.

488

489 The model testing dataset consisted of five different fMRI experiments: perceived speech,  
490 imagined speech, perceived movie, multi-speaker, and decoder resistance. In the perceived  
491 speech experiment, subjects listened to 5-15 min stories from *The Moth Radio Hour*, *Modern  
492 Love*, and *The Anthropocene Reviewed*. These test stories were held out from model training.  
493 Each story was played during a single fMRI scan with a buffer of 10 s of silence before and after  
494 the story.

495

496 In the imagined speech experiment, subjects imagined telling 1 min segments from five *Modern  
497 Love* stories that were held out from model training. Subjects learned an ID associated with each  
498 segment (“alpha”, “bravo”, “charlie”, “delta”, “echo”). Subjects were cued with each ID over  
499 headphones and imagined telling the corresponding segment from memory. Each story segment  
500 was cued twice in a single 14 min fMRI scan, with 10 s of preparation time after each cue and 10  
501 s of rest time after each segment.

502

503 In the perceived movie experiment, subjects viewed four 4-6 min movie clips from animated  
504 short films: “La Luna” (Pixar Animation Studios), “Presto” (Pixar Animation Studios), “Partly  
505 Cloudy” (Pixar Animation Studios), and “Sintel” (Blender Foundation). The movie clips were  
506 self-contained and almost entirely devoid of language. The original high-definition movie clips  
507 were cropped and downsampled to 727 x 409 pixels. Subjects were instructed to pay attention to

508 the movie events. Notably, subjects were not instructed to generate an internal narrative. Each  
509 movie clip was presented without sound during a single fMRI scan, with a 10 s black screen  
510 buffer before and after the movie clip.

511  
512 In the multi-speaker experiment, subjects listened to two repeats of a 6 min stimulus constructed  
513 by temporally overlaying a pair of stories from *The Moth Radio Hour* told by a female and a  
514 male speaker. Both stories were held out from model training. Subjects attended to the female  
515 speaker for one repeat and the male speaker for the other, with the order counterbalanced across  
516 subjects. Each repeat was played during a single fMRI scan with a buffer of 10 s of silence  
517 before and after the stimulus.

518  
519 In each trial of the decoder resistance experiment, subjects were played one of four 80 s  
520 segments from a test story over headphones. Before the segment, subjects were cued to perform  
521 one of four cognitive tasks (“listen”, “count”, “name”, “tell”). For the “listen” cue, subjects  
522 passively listened to the story segment. For the “count” cue, subjects counted by sevens in their  
523 heads. For the “name” cue, subjects named and imagined animals in their heads. For the “tell”  
524 cue, subjects told different stories in their heads. Trials were balanced such that 1) each task was  
525 the first to be cued for some segment and 2) each task was cued exactly once for each segment,  
526 resulting in a total of 16 trials. We conducted two 14 min fMRI scans each comprising 8 trials,  
527 with 10 s of preparation time after each cue and 10 s of rest time after each trial.

528

## 529 **Language model**

530

531 Generative Pre-trained Transformer (GPT) is a 12 layer neural network which uses multi-head  
532 self-attention to combine representations of each word in a sequence with representations of  
533 previous words<sup>18</sup>. GPT was trained on a large corpus of books to predict the probability  
534 distribution over the next word  $s_n$  in a sequence  $(s_1, s_2, \dots, s_{n-1})$ .

535

536 We fine-tuned GPT on a corpus comprising Reddit comments (over 200 million total words) and  
537 240 autobiographical stories from *The Moth Radio Hour* and *Modern Love* that were not used for

538 decoder training or testing (over 400,000 total words). The model was trained for 50 epochs with  
539 a maximum context length of 100.

540

541 GPT estimates a prior probability distribution  $P(S)$  over word sequences. Given a word  
542 sequence  $S = (s_1, s_2, \dots, s_n)$ , GPT computes the probability of observing  $S$  in natural language  
543 by multiplying the probabilities of each word conditioned on the previous words:  $P(S) =$   
544  $\prod_1^n P(s_i | s_{1:i-1})$  where  $s_{1:0}$  is the empty sequence  $\emptyset$ .

545

546 GPT is also used to extract semantic features from language stimuli. In order to successfully  
547 perform the next word prediction task, GPT learns to extract quantitative features that capture the  
548 meaning of input sequences. Given a word sequence  $S = (s_1, s_2, \dots, s_n)$ , the GPT hidden layer  
549 activations provide vector embeddings that represent the meaning of the most recent word  $s_n$  in  
550 context. Previous studies have shown that middle layers of language models extract the best  
551 semantic features for predicting brain responses to natural language<sup>13,14,16,17</sup>.

552

### 553 **Encoding model**

554

555 In voxel-wise modeling, quantitative features are extracted from stimulus words, and regularized  
556 linear regression is used to estimate a set of weights that predict how each feature affects the  
557 BOLD signal in each voxel.

558

559 A stimulus matrix was constructed from the training stories. For each word-time pair  $(s_i, t_i)$  in  
560 each story, we provided the word sequence  $(s_{i-5}, s_{i-4}, \dots, s_{i-1}, s_i)$  to the GPT language model  
561 and extracted semantic features of  $s_i$  from the ninth layer. This yields a new list of vector-time  
562 pairs  $(M_i, t_i)$  where  $M_i$  is a 768-dimensional semantic embedding for  $s_i$ . These vectors were then  
563 resampled at times corresponding to the fMRI acquisitions using a 3-lobe Lanczos filter.

564

565 A linearized finite impulse response (FIR) model was fit to every cortical voxel in each subject's  
566 brain. A separate linear temporal filter with four delays ( $t - 1$ ,  $t - 2$ ,  $t - 3$ , and  $t - 4$  time-  
567 points) was fit for each of the 768 features, yielding a total of 3,072 features. With a TR of 2 s  
568 this was accomplished by concatenating the feature vectors from 2, 4, 6, and 8 s earlier to predict

569 responses at time  $t$ . Taking the dot product of this concatenated feature space with a set of linear  
570 weights is functionally equivalent to convolving the original stimulus vectors with linear  
571 temporal kernels that have non-zero entries for 1-, 2-, 3-, and 4-time-point delays. Before doing  
572 regression, we first z-scored each feature channel across the training matrix. This was done to  
573 match the features to the fMRI responses, which were z-scored within each scan.

574

575 The 3,072 weights for each voxel were estimated using L2-regularized linear regression (also  
576 known as ridge regression). The regression procedure has a single free parameter which controls  
577 the degree of regularization. This regularization coefficient is found for each voxel in each  
578 subject by repeating a regression and cross-validation procedure 50 times. In each iteration,  
579 approximately a fifth of the time-points were removed from the model training dataset and  
580 reserved for validation. Then the model weights were estimated on the remaining time-points for  
581 each of 10 possible regularization coefficients (log spaced between 10 and 1,000). These weights  
582 were used to predict responses for the reserved time-points, and then  $R^2$  was computed between  
583 actual and predicted responses. For each voxel, the regularization coefficient is chosen as the  
584 value that led to the best performance, averaged across bootstraps, on the reserved time-points.  
585 The top 10,000 cortical voxels based on cross-validation performance were used for decoding.

586

587 The encoding model estimates a function  $\hat{R}$  that maps from semantic features  $S$  to predicted  
588 brain responses  $\hat{R}(S)$ . Assuming that BOLD signals are affected by Gaussian additive noise,  
589 recorded brain responses  $R$  and semantic features  $S$  can be jointly modeled as a multivariate  
590 Gaussian distribution  $(R, S)^{12}$ . The likelihood of observing responses  $R$  given semantic features  
591  $S$  can then be expressed as a multivariate Gaussian distribution  $P(R | S)$  with mean  $\mu = \hat{R}(S)$   
592 and covariance  $\Sigma = \langle (R - \hat{R}(S))^T (R - \hat{R}(S)) \rangle$ . The noise covariance  $\Sigma$  was estimated using a  
593 bootstrap procedure. Each story was held out from the model training dataset, and an encoding  
594 model was estimated using the remaining data. A bootstrap noise covariance matrix for the held  
595 out story was computed using the residuals between the predicted responses and the true  
596 responses. We estimated  $\Sigma$  by averaging the bootstrap noise covariance matrices across held out  
597 stories.

598

599 All model fitting and analysis was performed using custom software written in Python, making  
600 heavy use of NumPy<sup>34</sup>, SciPy<sup>35</sup>, PyTorch<sup>36</sup>, HuggingFace<sup>37</sup>, and pycortex<sup>38</sup>.

601

## 602 **Word rate model**

603

604 A word rate model was estimated for each subject to predict when words were perceived or  
605 imagined. The word rate at each fMRI acquisition was defined as the number of stimulus words  
606 that occurred since the previous acquisition. Regularized linear regression is used to estimate a  
607 set of weights that predict the word rate  $w$  from the brain responses  $R$ . Brain responses were  
608 restricted to the classical language network. A separate linear temporal filter with four delays  
609 ( $t + 1$ ,  $t + 2$ ,  $t + 3$ , and  $t + 4$ ) was fit for each voxel. With a TR of 2 s this was  
610 accomplished by concatenating the responses from 2, 4, 6, and 8 s later to predict the word rate  
611 at time  $t$ . Given novel brain responses, this model predicts the word rate at each acquisition. The  
612 time between consecutive acquisitions (2 s) is then evenly divided by the predicted word rates  
613 (rounded to the nearest nonnegative integers) to predict word times.

614

## 615 **Beam search decoder**

616

617 Under Bayes' theorem, the distribution  $P(S | R)$  over word sequences given brain responses can  
618 be factorized into a prior distribution  $P(S)$  over word sequences and an encoding distribution  
619  $P(R | S)$  over brain responses given word sequences. Given novel brain responses  $R_{test}$ , the  
620 most likely word sequence  $S_{test}$  that the subject is hearing or imagining could theoretically be  
621 identified by evaluating  $P(S)$ —with the language model—and  $P(R_{test} | S)$ —with the subject's  
622 encoding model—for all possible word sequences  $S$ . However, the combinatorial structure of  
623 natural language makes it computationally infeasible to evaluate all possible word sequences.  
624 Instead, we approximated the most likely word sequence using a beam search algorithm.

625

626 The decoder maintains a beam containing the  $k$  most likely word sequences. The beam is  
627 initialized with an empty word sequence. When new words are detected by the word rate model,  
628 the language model generates continuations for each candidate  $S$  in the beam. The language  
629 model is provided with the words  $(s_{n-i}, \dots, s_{n-1})$  that occur in last 8 seconds of the candidate,



630 and predicts the distribution  $P(s_n | s_{n-i}, \dots, s_{n-1})$  over the next word. Nucleus sampling<sup>39</sup> is  
631 used to identify words that belong to the top  $p$  percent of the probability mass and have a  
632 probability within a factor  $r$  of the most likely word. Nucleus words that occur in the language  
633 model input  $(s_{n-i}, \dots, s_{n-1})$  are filtered out, as language models have been shown to be biased  
634 towards such words. Each word in the remaining nucleus is appended to the candidate to form a  
635 continuation  $C$ .

636

637 The encoding model scores each continuation by the likelihood  $P(R_{test} | C)$  of observing the  
638 recorded brain responses. The  $k$  most likely continuations across all candidates are retained in  
639 the beam. To increase the diversity of the beam, we accepted a maximum of 5 continuations for  
640 each candidate. To increase linguistic coherence, the number of accepted continuations for a  
641 candidate was determined by the probability of that candidate under the language model.  
642 Candidates in the top quintile under  $P(S)$  were permitted the maximum 5 continuations.  
643 Candidates in the next quintile were permitted 4 continuations, and so on, with candidates in the  
644 bottom quintile permitted 1 continuation.

645

## 646 **Decoder parameters**

647

648 The decoder has several parameters that affect model performance. The encoding model is  
649 parameterized by the number of context words provided when extracting GPT embeddings. The  
650 noise model is parameterized by a shrinkage factor  $\alpha$  that regularizes the covariance  $\Sigma$ . Language  
651 model parameters include the length of the input context, the nucleus mass  $p$  and ratio  $r$ , and the  
652 set of possible output words.

653

654 All parameters were tuned by grid search and by hand on data collected as subject S3 listened to  
655 a calibration story from *The Moth Radio Hour* separate from the training and test stories. We  
656 decoded the calibration story using each configuration of parameters. The best performing  
657 parameter values were validated and adjusted through qualitative analysis of decoder predictions.  
658 The parameters values used in this study provide a default decoder configuration, but in practice  
659 can be tuned separately and continually for each subject to improve performance.

660

661 To ensure that our results generalize to new subjects and stimuli, we restricted all pilot analyses  
662 to data collected as subject S3 listened to the test story “Where There’s Smoke” by Jenifer  
663 Hixson from *The Moth Radio Hour*. All pilot analyses on the test story were qualitative. We  
664 froze the analysis pipeline before we viewed any results for the remaining subjects, stimuli, and  
665 experiments.

666

### 667 **Language similarity metrics**

668

669 Decoded word sequences were compared to reference word sequences using a range of  
670 automated metrics for evaluating language similarity. Word error rate (WER) computes the  
671 number of edits (word insertions, deletions, or substitutions) required to change the predicted  
672 sequence into the reference sequence. BLEU<sup>40</sup> computes the number of predicted  $n$ -grams that  
673 occur in the reference sequence (precision). We used the unigram variant BLEU-1. METEOR<sup>41</sup>  
674 combines the number of predicted unigrams that occur in the reference sequence (precision) with  
675 the number of reference unigrams that occur in the predicted sequence (recall), and accounts for  
676 synonymy and stemming using external databases. BERTScore<sup>42</sup> uses a bidirectional transformer  
677 language model to represent each word in the predicted and reference sequences as a  
678 contextualized embedding, and then computes a matching score over the predicted and reference  
679 embeddings. We used the recall variant of BERTScore with IDF importance weighting  
680 computed across stories in the training dataset. BERTScore was used for all analyses where the  
681 language similarity metric is not specified.

682

683 For the perceived speech, multi-speaker, and decoder resistance experiments, stimulus transcripts  
684 were used as reference sequences. For the imagined speech experiment, subjects told each story  
685 segment out loud outside of the scanner, and the audio was recorded and manually transcribed to  
686 provide reference sequences. For the perceived movie experiment, official audio descriptions  
687 from Pixar Animation Studios were manually transcribed to provide reference sequences for  
688 three movies. To compare word sequences decoded from different brain regions (Fig. 2d), each  
689 sequence was scored using the other as reference and the scores were averaged (prediction  
690 similarity).

691

692 We scored the predicted and reference words within a 20 s window around every second of the  
693 stimulus (window similarity). Scores were averaged across windows to quantify how well the  
694 decoder predicted the full stimulus (story similarity).

695  
696 To test whether stimulus time-points can be identified using decoder predictions, we performed a  
697 post hoc identification analysis using similarity scores between predicted and reference  
698 sequences. We constructed a matrix  $M$  where  $M_{ij}$  reflects the similarity between the  $i$ th  
699 predicted window and the  $j$ th reference window. For each time-point  $i$ , we sorted all reference  
700 windows by their similarity to  $i$ th predicted window, and scored the time-point by the percentile  
701 rank of the  $i$ th reference window. The mean percentile rank for the full stimulus was obtained by  
702 averaging percentile ranks across time-points.

703

#### 704 **Statistical testing**

705

706 To test statistical significance of decoding scores, we generated 200 null sequences by sampling  
707 from the language model without using any brain data. These sequences reflect the null  
708 hypothesis that the decoder does not reconstruct meaningful information about the stimulus from  
709 the brain data. We scored the null sequences against the reference sequence to produce a null  
710 distribution of decoding scores. We compared the observed decoding scores to this null  
711 distribution using a one-sided nonparametric test;  $p$ -values were computed as the fraction of null  
712 sequences with a decoding score greater than or equal to the observed decoding score.

713

714 To test statistical significance of the post hoc identification analysis, we randomly shuffled 10-  
715 row blocks of the similarity matrix  $M$  before computing percentile ranks. We evaluated 2,000  
716 shuffles to obtain a null distribution of mean percentile ranks. We compared observed mean  
717 percentile rank to this null distribution using a one-sided permutation test;  $p$ -values were  
718 computed as the fraction of shuffles with a mean percentile rank greater than or equal to than the  
719 observed mean percentile rank.

720

721 Unless otherwise stated, all tests were performed within each subject and then replicated across  
722 all subjects ( $n = 7$  for the cross-subject decoding analysis shown in Fig. 3e,  $n = 3$  for all other

723 analyses). All tests were corrected for multiple comparisons when necessary using the false  
724 discovery rate (FDR)<sup>43</sup>.

725

## 726 **Word decoding performance**

727

728 To quantify word-level decoding performance, we represented words using 300-dimensional  
729 GloVe embeddings<sup>44</sup>. We considered a 10 s window centered around each stimulus word. We  
730 computed the maximum linear correlation between the stimulus word and the predicted words in  
731 the window. Then, for each of the 200 null sequences, we computed the maximum linear  
732 correlation between the stimulus word and the null words in the window. The match score for the  
733 stimulus word was defined as the number of null sequences with a maximum correlation less  
734 than the maximum correlation of the predicted sequence. Match scores above 100 indicate higher  
735 decoding performance than expected by chance, while match scores below 100 indicate lower  
736 decoding performance than expected by chance.

737

738 Match scores were averaged across all occurrences of a word across six test stories. The word-  
739 level match scores were compared to behavioral ratings of valence (pleasantness), arousal  
740 (intensity of emotion), dominance (degree of exerted control), and concreteness (degree of  
741 sensory or motor experience)<sup>45,46</sup>. Each set of behavioral ratings was linearly rescaled to be  
742 between 0 and 1. The word-level match scores were also compared to word duration in the test  
743 dataset, language model probability in the test dataset, word frequency in the test dataset, and  
744 word frequency in the training dataset.

745

## 746 **Anatomical alignment**

747

748 To test if decoders could be estimated without any training data from a target subject,  
749 volumetric<sup>47</sup> and surface-based<sup>48</sup> methods were used to anatomically align training data from  
750 separate source subjects into the volumetric space of the target subject.

751

752 For volumetric alignment, we used the *get\_mnixfm* function in *pycortex*<sup>38</sup> to compute a linear  
753 map from the volumetric space of each source subject to the MNI template space. This map was

754 applied to recorded brain responses for each training story using the *transform\_to\_mni* function  
755 in *pycortex*. We then used the *transform\_mni\_to\_subject* function in *pycortex* to map the  
756 responses in MNI152 space to the volumetric space of the target subject. We z-scored the  
757 response time-course for each voxel in the volumetric space of the target subject.

758

759 For surface-based alignment, we used the *get\_mri\_surf2surf\_matrix* function in *pycortex* to  
760 compute a map from the surface vertices of each source subject to the surface vertices of the  
761 target subject. This map was applied to the recorded brain responses for each training story. We  
762 then mapped the surface vertices of the target subject into the volumetric space of the target  
763 subject using the *line-nearest* scheme in *pycortex*. We z-scored the response time-course for each  
764 voxel in the volumetric space of the target subject.

765

766 Each source subject independently produces a set of aligned responses for the target subject. To  
767 aggregate across source subjects, we used a bootstrap procedure to sample five sets of source  
768 subjects. For each bootstrap, the aligned responses were averaged across the sampled source  
769 subjects. To estimate the noise model  $\Sigma$ , aligned responses from a single, randomly sampled  
770 source subject were used to compute the bootstrap noise covariance matrix for each training  
771 story. Separate encoding models were estimated using volumetric and surface-based alignment.  
772 Cross-subject decoders were evaluated by decoding actual responses recorded from the target  
773 subject.

774

#### 775 **Data availability**

776

777 All data used in the analysis will be made publicly available at OpenNeuro before publication.

778

#### 779 **Code availability**

780

781 All code used in the analysis will be made publicly available at GitHub before publication.

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829 **Author Contributions**

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831 Conceptualization J.T. and A.G.H.; Methodology J.T.; Software and resources J.T. and S.J.;  
832 Investigation and data curation J.T. and A.L.; Formal analysis and visualization J.T.; Writing  
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835

836 **Competing Interests**

837

838 The authors declare the following competing interests: A.G.H. and J.T. have a provisional patent  
839 application related to this work.

840

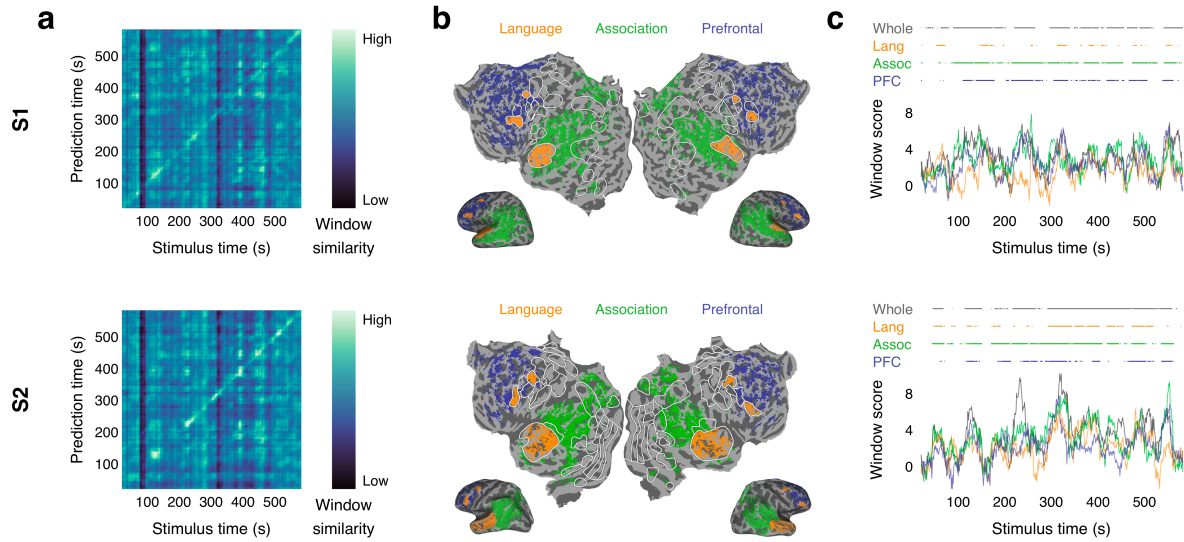
841 **Additional Information**

842

843 Supplementary Information is available for this paper.

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847 **Extended Data Fig. 1. Perceived speech decoding performance.** Language decoders were trained for subjects S1  
848 and S2 and then evaluated on single-trial BOLD fMRI responses recorded while the subjects listened to the test  
849 story “Where There’s Smoke” by Jenifer Hixson from *The Moth Radio Hour*. (a) Identification accuracy for whole  
850 brain decoder predictions. The brightness at  $(i, j)$  reflects the BERTScore similarity between the  $i$ th second of the  
851 decoder prediction and the  $j$ th second of the actual stimulus. Identification accuracy was significantly higher than  
852 expected by chance ( $p < 0.05$ , one-sided permutation test). (b) Cortical networks for subjects S1 and S2. Brain data  
853 used for decoding (colored voxels) were partitioned into the classical language network, the parietal-temporal-  
854 occipital association network, and the prefrontal network (PFC). (c) Decoding performance time-course from each  
855 network. Horizontal lines indicate when decoder predictions were significantly more similar to the actual stimulus  
856 than expected by chance under the BERTScore metric ( $q(\text{FDR}) < 0.05$ , one-sided nonparametric test).  
857 Corresponding results for subject S3 are shown in Figures 1f, 2a, and 2c in the main text.

## **Semantic reconstruction of continuous language from non-invasive brain recordings**

Jerry Tang, Amanda LeBel, Shailee Jain, Alexander G. Huth

### **Supplementary Information**

Table 1. Decoder predictions for a perceived story

Table 2. Decoder predictions for imagined stories

Table 3. Decoder predictions for perceived movies

Table 4. Cross-subject decoder predictions for a perceived story

Time (s)	Actual stimulus	S1 prediction	S2 prediction	S3 prediction
0	i reached over and secretly undid my seatbelt and when his foot hit the brake at the red light i flung open the door and i ran			
10	i had no shoes on i was crying i had no wallet but i was ok because i had my cigarettes	she said she was a little stressed out because she wasn't doing anything wrong and had a lot of anxiety issues but i had been	i don't have any friends that have one and i really don't care if you do i have a girlfriend i don't mind at all	we got in my car and i was crying i didn't have my purse i don't have any money to pay for gas i
20	and i didn't want any part of freedom if i didn't have my cigarettes when you live with someone who has a temper a very bad temper a	watching the news and realized that her mom was the most important thing to me and i was not a fan of this guy she was a nice girl i loved	when we do this it is the only thing i do for a living my entire life i'm always going to do something i	wasn't a very good friend to anyone that i had known since my dad was an alcoholic he was abusive to everyone and it was very
30	very very bad temper you learn to play around that you learn this time i'll play possum and next time i'll	her very much but i couldn't let her go without making it clear i wanted a relationship she would say no to everything and be willing to	love and do i can say it now with absolute conviction that you are doing what i want you to do in life is to	hard on me as well as him to do anything that he said or did i would say a word to him
40	just be real nice or i'll say yes to everything or you make yourself scarce or you run and this was one of the times when you just run and as	deal with anything just as long as it didn't mean something she was afraid of i did it a lot of times but never like this and	go out and enjoy the good times and make sure you're happy with the results you get to see them as they are because you have to have them at	in anger or a threatening way in his case it was always just an excuse to leave and that was why i did it and i think that when
50	i was running i thought this was a great place to jump out because there were big lawns and there were cul de sacs and sometimes he would come after me and drive and yell stuff at me to get back in get back in	now i see how she can make it work with a single phone call to the hospital my first instinct is to run over and kick her out of the room and say no you can	that point the next day you are on the street in a neighborhood with no sidewalk so you can't run off the road to escape the cops who have already started chasing you i didn't say no but i	i finally did i ended up moving to an area with very few houses on the property so the neighbors wouldn't hear my car stop in the driveway and run out and tell me to leave and not
60	and i was like no i'm out of here this is great and i went and hid behind a cabana and he left and i had my cigarettes and uh i started to walk in this	do this i refuse to go back there so i sit down at the dining table and i ask him what is the point of having the	said you can go around the corner to a nearby park i don't have a bike so i did and there was this little guy at	come back i said ok and went home to pack a bag i told her about it and she was like wow you know how you get on with
70	beautiful neighborhood it was ten thirty at night and it was silent and lovely and there was no sound except	house built on the beach at night it was a beautiful day i was going to stay at the house of my grandparents that was	the very top of it all and the main character in the book is a guy who is	a boyfriend after a couple weeks i went home and it was a beautiful evening and the party was getting really packed we
80	for sprinklers ch ch ch ch {ig} ch ch ch {ig} and i was enjoying myself	near a beach it was a perfect day so i	really into his music and plays guitar and video games for hours at a time	had a table set for six and two and so on after
90	and enjoying the absence of anger and enjoying these few hours i knew i'd have of freedom and just to perfect it i thought i'll have a smoke and	was just being nice to my friends i didn't get much of a chance to do anything until later that evening at am and i decided to take my phone	i can never forget that day and that moment that i lost everything i was to ever hope to be again and to my great pain and regret i will not allow myself to	the initial shock of what happened to us and our situation and all the things we did that day that we didn't do before i could even think about saying to myself
100	then it occurred to me with horrifying speed i don't have a light just then as if in answer i see a figure up ahead	out i was worried that my battery had died or something as i got it i looked around and saw a red light coming	feel pity for them and they deserve better i know this will get buried but if it ever comes out of this mess that my girlfriend had	how stupid that is i got my phone out to make a call when i saw a woman in the park i
110	who is that it's not him ok they don't have a dog who is that what uh what are they doing out on this suburban street and the person comes closer and i could see it's a woman	from the house my mom called out i know who that is i said we got there a few minutes before him and his girlfriend came to a stop in	her eye on when i got home it was because my boyfriend and i were leaving a house with no windows she was just in a car with us when she came to a	said to myself who is she i was just a guy with no job i didn't know anyone who lived in this neighborhood i walked in and saw her with a man
120	and then i can see she has her hands in her face oh she's crying and then she sees me and she composes herself and she gets closer and i see she has no	front of us the girl had her arms out and her head in my direction she looked scared and the guy just kept staring at me she turned around and i saw	stop i noticed that her hair was missing she looked at my hand and then up at me she started crying she pulled away from me and i could see she was in	who was staring at her chest with his hands in the air she then noticed me and her face turned bright red she quickly looked away and i walked in to see her crying and

Time (s)	Actual stimulus	S1 prediction	S2 prediction	S3 prediction
130	shoes on she has no shoes on and she's crying and she's out on the street street i recognize her though i've never met her and just as she passes me she	her face she was in a black suit i just had a bad feeling that she knew me from somewhere but she didn't know me at all she looked	pain but it wasn't her blood it was a woman in a white dress who was very clearly not human and then she came up and asked if we	shaking she was a girl i knew from high school and still was very much like her and her dad i know you don't remember her but we talked and
140	says you got a cigarette and i say you got a light and she says damn i hope so and then sh first she digs into her cutoffs in the	at me and asked if i wanted a beer but i told her i couldn't so i got one out of my backpack and poured it down	had any money she said she had some for us and i told her no i had never heard of this girl i knew	i asked her if she had any money i said i didn't know so she took a purse off the top of
150	front nothing and then digs in the back and then she has this vest on that has fifty million little pockets on it and she's checking and checking and it's looking bad it's looking very bad	her shirt the top button was ripped and there was a piece of paper stuck in there with a bunch of random numbers and words i couldn't understand at all so i	that she had been telling people in school about me for about two years and the stories had spread to her friends and it was never mentioned to anyone else about the	her closet and pulled out a tiny pair of pants with holes in them she also kept a bunch of random things in there but nothing really helpful i eventually made it
160	she digs back in the front again deep deep and she pulls out a pack of matches that had been laundered at least once ukgh we open	got down to the first two boxes and pulled the top off one was filled with a pile of money that was still in there so	other times i would go out and meet people and feel comfortable and normal in a strange city or something like that so i	to the other side and found a large flat tire that i thought might have been broken the whole time and had
170	it up and there is one match inside ok oh my god this takes on it's like nasa now we got to like oh how are we gonna do it ok and we we hunker down	he took it back and said sorry about this i don't think anyone can help you now it's all done now so it would be better to be	got my car fixed and had a few beers to pass the time and i had to be there at pm so i just sat there with the car	to be fixed so i gave it back i just couldn't lose it it was worth a shot the best way to go is to take a deep breath and push
180	we crouch on the ground and where's the wind coming from we're stopping i take out my cigarettes let's get the cigarettes ready oh my brand she says not surprising and	able to see the light from the sky then it's my turn to help him pick up his shoes i suggest taking them off as he is	door open and the battery in my hand i could hear him say you can use it for gas my mom just said you know the power	off the ground and to get a solid hold of the tree i got it right and my dad yelled i need your help with this he said that
190	we both have our cigarettes at the ready she strikes once nothing she strikes again yes fire puff inhale mm sweet kiss of that cigarette	about to fall so he goes for it he drops them and they are immediately shot and blown to pieces as he walks	goes out at this point and it takes off with a loud pop and a puff of smoke from the pipe as i	was my best shot and he took the needle and filled it with blood and let it flow over my arm like a warm
200	and we sit there and we're loving the nicotine and we both need this right now i can tell the night's been tough immediately we start to reminisce	away and i sit down with my wife to be able to see what happened the whole time my husband was at the hospital for about two weeks	grab her and hold her down and i try to get her to eat some food because it is all i could find after about minutes of this	bath and then i sat down to have my body relax and enjoy the moment as my friend and i were on a journey through our first day of training he
210	about our thirty second relationship i didn't think that was gonna happen me neither oh man that was close oh i'm so lucky i saw you yeah then she	while his wife was in surgery when he called me i said you know what you did right and that was when i got	i say to myself how are we going to get home i don't see anyone i yell hey where is everybody and the guy starts	asked if he could watch my face during the whole thing i said sure i had been there for him and he had to come and see
220	surprises me by saying what was the fight about and i say wha what are they all about and she said i know what you mean she said was it a bad one and and i said	an email from the girl asking me if i had heard of this i said no i did not the reply was you don't know of course	to look around and says what happened to him i said what did you mean i don't know but he replied you did see him he looked	me because he was at work i asked him what happened i said you don't know who he is did he say yeah i mean no he
230	you know like medium she said oh and we start to trade stories about our lives we're both from up north we're both kind of newish to	not and we laughed and i got a call from a friend in the same town we lived in that had a small local	really pale and scared i walked over and we started talking about our experiences in the area he was born in i was from the north of the	didn't he was a bit vague i had a conversation with him last year at a club in town we were both from the us
240	the neighborhood this is in florida we both went to college not great colleges but man we graduated and i'm actually finding myself a little jealous of her because she has this really cool	college on the east coast and was an engineering school with a great program they were pretty good people but there was one who seemed really into it and started talking about his	country and the city we live in was a state university he grew up in he is a pretty smart guy but i guess the fact that he was an engineer for a company that	and had met in high school and college i was a year older and a good looking girl in my eyes but she had a lot of other interests she was into computers
250	job washing dogs she had horses back home and she really loves animals and she wants to be a vet and i'm like man you're halfway there	degree in art history he had a phd and he wanted to teach a new language i told him no way he should be	does electrical work and he has a job that makes money i used to be a computer science major i would have been fine	and programming and was a teacher in an engineering school but that wasn't enough to make a career in

Time (s)	Actual stimulus	S1 prediction	S2 prediction	S3 prediction
260	i'm a waitress at an ice cream parlor so um that's not i don't know where i want to be but i know it's not that and then it gets a little deeper {cg}	working in an engineering lab with a phd but i didn't say that i wasn't happy about it and i was in the middle of	as a teacher but the internet is not for me so i guess that was for a while and i started getting to know	physics or even a job at a university so i don't have much time for this but i wanted to say i would
270	and we share some other stuff about what our lives are like things that i can't ever tell people at home this girl i can tell her the really ugly stuff and she	a presentation with some people who were coming up for their first visit to a new place i had already told her i wanted to be friends but she seemed to	a few people but i have been very open with the person in question and have found that their response to everything is usually positive and that they	like to see a couple of things about how it works i will try to describe to you the way that i would think about the situation to explain how
280	still understands how it can still be pretty she understands like how nice he's gonna be when i get home and how sweet that'll be	not feel the same way about it the thing is when you find out you're not good enough for someone to love you and	don't judge anyone for being happy and healthy but they do always think of people who have bad experiences or are too afraid to stick it out	i feel in my mind it will make sense to me how it felt to know that the other person is hurting because of me so i
290	we are chain smoking off each other oh that's almost out come on and we we go through this entire pack until it's gone and then i say you know what uh this is a little funny but you're gonna	you just have to fight the urge to throw the ring back in the box and take your pick of the two and set them free but i can't i need	so i tried to give a few of them a shot and then put them on hold while i finished it i took a sip and said i need to call	let my friend have a go at it and she gets it right and starts to blow her load it goes down and we both laugh i say i need to take this
300	have to show me the way to get home because although i'm twenty three years old i don't have my driver's license yet and i just jumped out right when i needed to and she says well why don't you come back to my house and i'll give you	to ask you something about my childhood i had to get my license to drive so my mom could have me out of the house and she wanted me to go with her to visit my dad	a cab because i can't get to work in my condition i'm not sure if my body would allow me to walk back home so i decided to call a friend and ask him to drive	back but she is not ready she has not even started to learn to drive yet i had to push her out of the car i said we will take her home now and she
310	a ride i say ok great and we start walking and uh we get to this um lots of uh lights and uh the roads are getting	so we left and got back home and it was then that i noticed something was different about the way the light was	me there he said ok and we headed over the hill and through a small valley the woods became smaller and then	agreed and we took off again and this time we went in the direction of her house to go look for a car so as i
320	wider and wider and there's more cars and i see um lots of stores you know laundromats and dollar stores and emergenciers and	changing around me and i looked up and saw a tall building with a few towers and a white flag flying above it and then	a clearing and a road we saw a few houses with a gas station and some stores and the next town we	drove we started talking about what to do next i was driving through a neighborhood of small businesses and a grocery store and
330	then we cross over us one and uh she leads me to some place and i think no but yes carl's efficiency	we came across a town about miles from our house and i thought oh god it was my grandmother the	drove down and around the last corner and we saw it i said wow and it was a car of	saw a truck pass on the highway that was about to hit me i knew what i was doing i had driven through a
340	apartments this girl lives there and it's horrible and it's lit up so bright just to illuminate the horribleness of it it's the kind of place where you drive your car right up and the door's	old lady from the church that was so very special to us but it was very sad because it meant that she had a death certificate she was	a man i know he is a great guy who works very hard to keep the place clean but his house is in an area where people do not	town that was a pretty big city with a lot of small businesses that were basically homeless people living in a place that had the worst environment possible when you
350	right there and there's fifty million cigarette butts outside and there's like doors one through seven and you know behind every single door there's some horrible misery going on there's someone crying or drunk	on the front page of every newspaper and it was just the top of the times which meant that there were stories of her being beaten at her job and having a	leave their furniture on the floor and other stuff and the walls are covered in photos of kids my age in various situations or places of extreme physical and mental abuse and some of	walk through a door with a broken window or in the front of an apartment building you probably think they are all dead or dying or just really stupid people
360	or lonely or cruel and i think oh god she lives here how awful we go to the door door number four and she very very quietly	boyfriend who beat her up but he wasn't that bad to begin with so i went to the cops i had to walk out of there and	them are really horrible to my mom i don't know why i do this i was a good kid and i got out of my	you are wrong all of them are crazy i just hope i am right so i can make an informed decision to just drop
370	keys in as soon as the door opens i hear the blare of television come out and on the blue light of the television the smoke of a hundred cigarettes in that little crack of light	take my chances and i got into a car that was sitting there the passenger seat was full of beer bottles and the front windshield had glass in it and	room when my mom called i answered the door and the smell of a very strong pot was immediately in front of my nose and my mother had been	everything and just take off i had been sitting in the lobby of my dorm with my headphones on and the sound of a female voice in my

Time (s)	Actual stimulus	S1 prediction	S2 prediction	S3 prediction
380	and i hear the man and he says where were you and she says never mind i'm back and he says you alright and she says yeah i'm alright	my mother was screaming at my father and saying oh no you aren't leaving us he said well why not i looked	drinking all day i was like hey mom i'm home and she said what are you doing you wanna come out she asked i didn't think	ear was the same as before she says hey are you busy i'm sorry i don't know you and i said yeah well i'll be right
390	and then she turns to me and says you want a beer and he says who the fuck is that and she pulls me over and he sees me and he says oh hey i'm not a threat	at my dad who was smiling i told my mom to call him back and when he finally answered she said no thanks my dad	so she called her boyfriend and he told her no but i thought i saw him look over at me he said oh she must be mad	there ok you guys want me to bring some drinks i looked at my friend and he shrugged i told her no she didn't like beer so
400	just then he takes a drag of his cigarette a very hard hard drag you know the kind that makes the end of it really heat up hot hot hot and long and it's a little scary and	had some sort of breakdown and just threw up for days it was a very serious form of depression that was going around and i had to put	but then he turned his head and started to cough up more blood then the last breath that he took before dying the same way i had before	she got another one and started getting the same kind of buzz in and out of her mouth and it was hard to stop it and the
410	i follow the cigarette down because i'm afraid of that head falling off and i'm surprised when i see in the crook of his arm a little boy sleeping	my hands up to hide the fact that i hurt to have it pulled up the skin on the side of my face and over my eye	i fell i felt the pressure on my chest i saw it as if in slow motion my face was pressed against a tree trunk as a	pressure built and she was pushing my hand down into the water and then suddenly i realized that my fingers were on top of a rock and
420	a toddler and i think and just then the girl reaches underneath the bed and takes out a carton and she taps out the last s pack of cigarettes in there	my dad said what is that he walked up to my father grabbed the shotgun from his side and started loading it with	child i was so excited i ran to the front porch and grabbed a small plastic box of my favorite christmas cards and	i was leaning over and then the first of my friends showed up with a large metal box and some tools to remove the top of it and put
430	and on the way up she kisses the little boy and then she kisses the man and the man says again you alright and she says yeah i'm just gonna go out and smoke with her and so	rounds i immediately pulled my brother to me and hugged him i then asked my sister if she could stay with us we all left to go get our cars and	started running up the steps and over to my mom my dad is right behind me and he says so i want to buy a few things so we start going through	it on the ground next to my brother and i was still crying i said thank god you guys were there you were awesome i told him we would help him through this we
440	we go outside and sit amongst the cigarette butts and smoke and i say wow that's your little boy and she says yeah isn't he beautiful and i say yeah he is he is beautiful	drove to the beach at am on the way back he said i can't believe this i don't understand it i'm like oh man you must be	the various bags in the back seat i have one of my old shirts and i say hey man you guys look awesome and you know i	went over the events of the previous day and he said it was a dream i was like how was he real and how he was so
450	he's my light he keeps me going she says we finish our cigarettes she finishes her beer i don't have a beer cause i can't go home	really special if you're the best thing in my life and i can barely speak i will probably never have sex again for fear of	love you and he replies yeah and so does his wife they get married and the girl who has a history of drinking and being	beautiful and what he did with the girl was that he didn't have a girlfriend he couldn't have kids or had to get them on
460	with beer on my breath and she goes inside to get the keys she takes too long in there getting the keys and i	becoming addicted to the stuff and then it gets worse when she comes out of it i start to worry that something is	in a bad relationship so i went out to eat and got some food when i came back in	birth control or anything then the day came where they got really scared and freaked out because i didn't show
470	think something must be wrong and she comes out and she says look i'm really sorry but um like we don't have any gas in the car it's already on e and he needs to get to work in the morning and um	wrong but then she says to me hey do you think she can afford to pay rent on time to a school for her kids to go to and	he had already left he didn't even bother to check the time he said that the cops didn't like the state he was in and they couldn't find the address in	up they told me to leave and i said i'm sorry but i couldn't i had a family emergency at work i don't have time to drive
480	i you know i i'm gonna be walk to work as it is so what i did was though here look i drew out this map for you and you're really you're like a mile and a half from home and um if you walk three streets over you'll be back on that pretty street	she would just say oh sorry i did the math on this one i will send her a link to a different site in the same time period to see how far back	the system i told him to stay there i could give him directions but that it was a few blocks away and to drive down a side street which would take him around the	home so i said i would get a ride i asked for directions and drove the distance i could see that there were about miles of traffic to go down the hill to where i lived
490	and you just take that and you'll be fine and she also has wrapped up in toilet paper seven cigarettes for me a third of her pack i note and a new pack of	she gets so i do this too i put a bunch of photos in an envelope with a few other stuff i brought a box of	corner i then pulled out a piece of paper that was taped to the steering wheel the one with the red pen she gave me	i turned left and pulled over i took out a pack of gum and a paper plate with a handful of fries i put a half a

Time (s)	Actual stimulus	S1 prediction	S2 prediction	S3 prediction
500	matches and she tells me good bye and that was great to meet you and how lucky and that was fun and you know let's be friends	them and he thanked me again then we started to talk about our life and the family he was from and i	and i was thinking that was really cool and she asked me for my number i said i would call her and	dozen quarters in and he said hey man i am so glad to meet you and we will see you soon okay i
510	and i say yeah ok and i walk away but i kind of know we're not gonna be friends i might not ever see her again and i kind of	said yes and then i got angry when i thought about it because i wasn't sure what was happening i didn't really care at all	i was like yeah i'm sorry and hung up i couldn't really be friends with her but i didn't know her very well and i never thought that	replied and she said ok bye i was kind of nervous to go in there but i knew what was happening and it was something that was very common in a
520	know i don't think she's ever going to be a vet and i cross and i walk away and maybe this would've seemed like a visit from my possible future and scary but it	until i saw it was the girl from my dreams that was driving down the road and i started to notice that the car was a bit older than my own i couldn't	she was very interesting to be around either i was in the process of going back home when i heard this story that made me a little sad because i	school and that i was just starting out in the field of physics but i felt that my experience with the subject had changed from my own personal perspective to
530	kind of does the opposite on the walk home i'm like man that was really grim over there and i'm going home now to my nice boyfriend	make it out clearly so i yelled hey you have to stop i just saw a man that i knew in the past who was very physically	felt that i could be honest with them i said to them you guys have been my friends and i am a man in love with	the reality i was in i could see what was going on but the real world was still around me it was the dream of being the father of
540	and he is gonna be so extra happy to see me and we have a one bedroom apartment and we have two trees and there's a yard and we have this jar in	abused by his wife she had him committed and was now living in his bedroom where he had a couch and tv the apartment was about feet long and had	my girlfriend she is a beautiful woman but we were living in a tiny apartment with only one bathroom and a single bedroom there were two rooms	a beautiful and intelligent young girl i was in a huge house with my own bedroom with two beds and a small bathroom that had a toilet and shower my
550	the kitchen where there's like loose money that we can use for anything like we would never ever run out of gas and um i don't have a baby you know so i can leave whenever i want	two bathrooms and a huge closet to store the clothes i didn't have any money or food because i wasn't hungry i was lucky my parents didn't lock me up so	for rent that we could afford on a monthly basis and our food was cheap we did have the option to live together but my dad never wanted it to happen so we always	parents bought me a big box of stuff that they could sell for pennies in my name because i didn't have a job they never cared and didn't really want me around anyway
560	i smoked all seven cigarettes on the way home and people who have never smoked cigarettes just think ick disgusting and poison	i just started drinking all the time the day before thanksgiving and my mom told me that the reason she doesn't like alcohol is because it's addictive i don't	went for a drive each night and talked about it over dinner i didn't realize that the fact that she had said it was so easy to	they paid my bills for months and years after the first time i told my wife she was an alcoholic she said that it would kill her
570	but unless you've had them and held them dear you don't know how great they can be and what friends and comfort and kinship they can bring	drink it much because i have been told not to but it can do something for you it's a wonderful drug that gives you an edge to deal with your anxiety	forget how she felt when we were together was amazing i still think of it as an incredible moment though as the time to share it comes and	if she got addicted to that stuff it made her want to do drugs that were very popular with people she knew and talked to for years after
580	it took me a long time to quit that boyfriend and then to quit smoking and uh	and emotions and then makes it so you can continue on with life after you graduate or die a couple years after your retirement in fact in most	i get to say the words and the scene changes to this video and then the other camera follows as a young guy stands there	she finally gave up on dating and married him the relationship ended with her and i with the kids at this
590	sometimes i still miss the smoking	cases it's a pretty common	on the street and watches	point it was very much

**Supplementary Table 1. Decoder predictions for a perceived story.** Language decoders were trained for each subject and then evaluated on single-trial BOLD fMRI responses recorded while that subject listened to the test story “Where There’s Smoke” by Jenifer Hixson from *The Moth Radio Hour*. The actual stimulus words are shown alongside the decoder predictions for each subject. Highlighted segments were significantly more similar to the actual stimulus than expected by chance under the BERTScore metric ( $q(\text{FDR}) < 0.05$ , one-sided nonparametric test). The decoders recovered the meaning of the perceived story.

Time (s)	Imagined stimulus (Alpha)	S1 prediction	S2 prediction	S3 prediction
0	every morning i woke up with two giant animals nuzzling me panting in my face demanding to be walked i would walk them	he was not happy with the idea of me being on his couch and sleeping with him and then when he had the chance to leave me in	it would be easier to just throw her over my shoulder and leave as she is already dressed and ready for bed when she calls my phone at	we need to know who it is and if they are coming to pick up my girl i will go and call her right away because i want to see her for
10	and upon my return i'd check the phone hoping i had somehow missed my wife's call saying that she had changed her mind and was moving back she never did	the hall and i saw his face when i said something to him that he couldn't remember and he asked me to come in he didn't really know	am to say that the police are there to talk to me about what happened she was right but not the end result i just had to move on	some reason i thought maybe she would come to me and say she misses me but no she was dead when i found her this is the truth i was in
20	i tried to carry on i bought groceries said hello to the neighbors i can see now that i was in	me i had a bad experience with drunk drivers at my college and that was all it was the worst part about it i don't	i started going to school and the people around me would say i was depressed and not happy it was like the world was ending i had	the hospital and my parents were at my house we had a party with my family and the doctors and nurses and everything but
30	shock pretending everything would be ok the house deteriorated the laundry hamper overflowed	remember anything about the accident the car was spinning in the air and the windshield was cracked and i was hanging out of it the front	been living on a diet and on the side of a toilet and a bottle of water and the bottom of my	we got through it just fine because of that we don't have insurance i had an accident on my bike with a tire iron and a
40	bags of trash clustered in the kitchen my bed was a sleeping bag dog hair accumulated in giant clumps in the corner of rooms and in	passenger side was just a piece of broken metal and a few others were scattered everywhere and the back door was open i knew the next	shoe on the ground my socks are covered in the sand and mud of the driveway the only time i have to	broken back in the process my father died and i had to leave to help him his funeral was a lot like what you hear on television people
50	filthy patches on the rug i was commuting an hour each way for work and unmoored from my previous life couldn't manage my responsibilities	step was to find a doctor and get help i started to cry and run i ran home i stayed up late until my alarm went off and	drive from one point to another is to the last stop i make in town and to my surprise i don't have a ticket for that one	are all over it all of them but not everyone is interested in you it gets a little confusing to be a single person

Time (s)	Imagined stimulus (Bravo)	S1 prediction	S2 prediction	S3 prediction
0	when my son jeff was little he was a pain in the neck about eating on one drive to huntsville alabama he	they got to the point where they were not in any condition to drive and were having a panic attack when i asked her why they	it is my favorite place to spend an evening because of the music it was playing during the concert that made me want to scream in the night at how stupid that	it is a very serious matter i am very concerned with how much time you will spend in jail and i do mean a month and a half ago i would say that
10	sobbed for seventy minutes i know because i timed it about how we were starving him to death we stopped at a diner and ordered him a meal and he	had to call her in to help out she just looked at me with those eyes and said please do not leave my husband is very upset	song was i thought about telling her but i decided to wait i went home and got some more weed i didn't think she was going to drink i just	if you get into the car and drive to a restaurant in the middle of nowhere and order a beer that is where the food is we decide to take turns with
20	proceeded to eat about four bites before claiming he was full you might think i would lose my temper but this had happened before so i was prepared	i think he wants to tell me something but he isn't sure i will agree or even respond in kind so he starts with me having sex with him but	felt bad and hoped she wouldn't take it i told her it was okay she took the bottle from me and started drinking it as i held it up	the bill and it comes off as a dollar i then give it to him as i don't want it anymore but it seems like the customer should
30	with a well planned response i reached over and started eating his food bite by bite i finished everything on his plate figuring	i don't feel anything i say that was wrong and i really wanted it to be true but he wasn't telling the truth the guy who did this was	i had to give her some more because she had already had it but i knew this was going to be hard for her to handle i did this	get a taste of this kind of treatment so i could be on my way i didn't do it all at once or even by
40	that would teach him to mind his dinner unfortunately the plan had a different effect everywhere we went after that jeff expected me	in prison and we just assumed he had the ability to do that because of how long he lived i got out of there and started moving	to her for over years i know that if she ever had a boyfriend or girlfriend it would be different because i never thought it was possible she had to	accident but the timing was right and it was my choice not to have my father in jail for not getting a job that i could have
50	to finish his meals it got so i would only order him meals i liked knowing how it would go	around in a new city and then bam they got the phone number and called me at work they had	be very close to a male of my own race so i wasn't as much of a threat to their	used my entire adult life as i had it before my parents had a panic attack when they had to get to work but i still did



Time (s)	Imagined stimulus (Charlie)	S1 prediction	S2 prediction	S3 prediction
0	for my third date with tracy i'm taking her to the sum hey rice shoppe in manhattan you're going to love this place i tell her when i was a kid i used to order pork chow	it was the night before the funeral that i decided to tell my dad he would understand but i was young and in love with the girl at the time we had	i was at a bar and this woman i know who is my friend and who i like a lot tells me to drink this and she	i had a dream about my best friend in college and he told me about a story he had read recently and i was there for him as he was
10	mai fun and smear it on the plate with ketchup tracy beams at me from the passenger seat she clearly likes that i'm already sharing family stuff	a small plot of land and was building it up in our backyard with some friends she was an incredible cook and always wanted to help us out	puts some in my cup and i feel my face turn red she was laughing and it was a great time so i say excuse me and	sick so i offered him a cup of tea i could smell the sugar and it made me smile because i was already getting better at
20	i wait for the pedestrians to clear before turning off canal onto mott at bayard i take a left there's the restaurant i say you want to get out and i'll go	with something as a teenager my dad got her into the kitchen and then to the other room so that we could get to work he said we	leave her i get into the car and drive off the main road into a town on the way home and pull in my dad says ok go ahead and	this i didn't think it was fair to take my job too seriously but the boss said i could
30	park nah says tracy i'll help you find a spot ok	should do this and i told him no i can't and that he should leave we ended up making the deal i don't think we went into	stop my mom asks me to just take a shower i reply oh no that's fine she said i should get some rest i say sure and i head down	go and he was right so i went i spent about minutes looking for the place and came up empty and then i realized that the door was not locked
40	i drive to the end of bayard but there are no spots at bowery i swing a right then at pell another right	it directly but the first week we did go to a movie a few of us had been to it before but i remember it	stairs and down the hall and turn left and right and then down a couple of floors and finally around another corner and there it	i started to walk away and the guy said hey you want some of my beer i don't need it he says it again i can't
50	there's what looks like a spot but when we get closer i notice a two pronged fire hydrant protruding from a brick wall nothing on pell i	was really creepy as hell with a giant snake on a string and all it had to do was come and eat me i don't think	is again i was almost sure it was the same one it had a very similar looking body type but i could have been wrong because	really hear you i'm not drunk i get it this time i actually do see it all in slow motion and i can feel the

Time (s)	Imagined stimulus (Delta)	S1 prediction	S2 prediction	S3 prediction
0	that spring was promising to be the greatest time of my life i was happily in love for the first time i	they are the same in the real world i was going to tell her about this when i saw the pictures of my wife she looked absolutely beautiful and	they will never be the same after i lost my dad he was my first friend and i knew nothing about him except for how	we were on vacation for a month and were very much in love with the idea of a little girl and a baby she was absolutely beautiful and
10	saw marko at school and was attracted to his eyes and playful smile one afternoon while walking home from a piano lesson	was sitting with her boyfriend in a movie theater with him we all were on a couch and he was holding her hand while he looked at her pictures i knew	to say it he had this huge tattoo on his arm and a really cute girl who was with him when we walked in and saw his	very independent and when they were gone she would sit up and look around the house and just get upset when i left to go
20	i saw him coming down the hill on his skateboard he stopped just short of running into me i don't remember us saying	my parents were worried so i asked him how he could tell his story he was very emotional and had to hold himself back i said i have	friend on the ground with a knife he immediately jumped in the car and pulled him away we all sat in silence and i said something to him i think i'm just	to school i ran into a man on his way to work that he was heading towards his car in the middle of the morning and told him what happened and how i had
30	much we just stood there and smiled but that's all it took to seal the deal and we became inseparable	never been happier and we went to the park and the dog ran out in front of a car and started biting and tearing at it i saw	stressed out from this day forward and that we could discuss it at my parents place or somewhere else for example we had a group of friends who would take	been the victim and what i did not know was that he had taken me to a friend of mine and i was brought to him and the other guys by
40	one day a group of us decided to climb an abandoned building and jump off its flat roof i was standing on the edge	a man go flying through the air and i thought to myself you want to live that fast but what happens when he lands you only have seconds before the wind rips	a ride down to the river and then drive back up the hill and sit on the rock facing the water while it comes up my friend starts crying he	my boyfriend and his girlfriend he was there with me for most of it i had to wear a shirt in a lot of ways that he hated to see
50	twelve feet above the dirt my heart racing when marko scooted next to me you are the bravest girl i know he whispered with those words my fear	you apart and then you're gone forever but even then it doesn't last i just went from the best friend who would	runs up to me and hugs me tight and whispers you saved me i just had a thought that was like the one where the person on the other side	so he could look at me like i was ugly he even offered me his hand which i took i felt so small in that moment i just didn't

Time (s)	Imagined stimulus (Echo)	S1 prediction	S2 prediction	S3 prediction
0	to reach chimi you take a dirt road then walk through wheat fields across a stream and past timber houses until you climb a small rise and	she was still on the road but in a better part of town we passed by a sign for an old school that had a huge tree	it to be able to walk back home in a straight line or in the direction of a house on a hill without breaking into a run the	he was on the road for about hours and his phone battery was dead we decided to go to my parents house and he went to mine since the
10	find an unprepossessing building surrounded by the usual troika of himalayan temple attendants dogs scratching at fleas chickens scratching at dirt and monks	house and a little girl riding her bike i said sorry and turned away it was just a game i thought i could get used to i	police report shows a large red and yellow crime scene tape with the name of a local law firm of cops with a black and white id on	one i had at home was just for the kids he was so nice and so gentle but when he left his house that was all there was i could
20	scratching at well it's not clear their robes cover quite a lot it was a pleasant place but nothing out of the ordinary i gave a prayer	got the car back and i was able to drive to work with my head down i drove by a police station with the license plate of the cop on	their shirt i didn't like it when they were there either so i said well it's too bad because i'm just going to throw a fit i just	do my part he had a small car that i knew he liked so we drove to the restaurant and he opened up the door and took a
30	wheel a lazy spin and even yawned as i walked into the central chamber in front of us loomed a smoky altar of goddesses at their feet lay offerings of	the side i turned the corner and saw him and the other two cars and one other guy with a baseball bat i was floored the	threw my hands up and walked out i was only at that point and my mom was coming out the door of the room in the corner i just knew it was going to be	deep breath i sat there awkwardly in the passenger seat for the next few minutes with the engine running but after a couple hours i had to
40	currency garlands of flowers candles fruit the room hummed with flies and noise and tourists but it was also full of an	cops were calling it a hit and run and my brother was still alive they were very respectful and very calm in my family they all thought it	bad and i had to do it so i slowly lifted the cover and saw my favorite piece of cake and chocolate chip ice cream	stop because of the smoke i started coughing and the smell of my own body filled the house it was like an animal attack i was
50	incredibly concentrated hopefulness something so spirited and real to me that i was brought uncharacteristically to my knees	was ok to talk about it and if you didn't feel comfortable enough you just asked and you know what i felt like i did a	i had just eaten i could see a giant cloud of smoke and heard people shouting and some kind of noise but i just kept walking towards	completely overcome and it wasn't a very healthy and natural thing i couldn't get over the experience of seeing the girl in a hospital bed for

**Supplementary Table 2. Decoder predictions for imagined stories.** Language decoders were trained for each subject (using data collected during story perception) and then evaluated on single-trial BOLD fMRI responses recorded while that subject imagined telling 1-minute segments from five different test stories from *Modern Love*. The story segments that the subjects were instructed to imagine are shown alongside the decoder predictions for each subject. Highlighted segments were significantly more similar to the reference stimulus than expected by chance under the BERTScore metric ( $q(\text{FDR}) < 0.05$ , one-sided nonparametric test). Decoder predictions were also significantly similar to transcripts recorded from each subject ( $q(\text{FDR}) < 0.05$ ; not shown). Results are shown for the second repeats of each segment; results for the first repeats were similar. The decoders recovered the meaning of the imagined stories.

Time (s)	Description ("La Luna")	S1 prediction	S2 prediction	S3 prediction
0	now over calm waters stars twinkle in the night sky a rowboat glides into view bearing the name la luna as a burly man with			
10	a thick brown mustache works the oars a little boy peeks over the side of the small wooden craft an old man with a long white beard sits near the stern a hanging	it was a beautiful summer day and a pretty girl was standing there and we had to wait at the bottom of a hill for	he is the man of the house and a gentleman in the family the same as your grandmother if i were to meet you on the street and	it was a small thing but i did feel for the man the story of how he died and how the doctors found the
20	lantern behind him a bird's eye view shows the boat moving steadily across the ocean's dark surface with no land in sight the burly man sets his oars inside	a taxi which wasn't easy considering the nature of the job so i have no idea what they do with the money and it is difficult to imagine the	see you walk away in my mind it would be the exact opposite i was at a bar with two guys and one girl when the first	cause of death the same way as if you had actually committed a crime with that amount of blood i went into a room and put a
30	the boat and the old man drops an anchor the old man hands the boy a gift he unwraps it to find a brown newsboy hat	company that works with it so many people just walking around the store doing nothing the owner just gives me a smile and says come in and	of them grabbed a glass and filled it with the cheapest beer and asked me to step in he said to me and his two sons if you	blanket over it and left my buddy in there with her and my friend she started crying and he took her in he told me about his little sister who
40	just like his dad and grandpa's he tries it on the old man turns the boy his way and lifts the hat's brim his father lowers the brim to be like his the	i just like to hang out with these two i was one of them for about a month we both had a history together we would have sex but	can put on a pair of socks i did they were a size too small he gave me a hug and then turned to his younger brother he	was now his wife he had a young daughter and she was very pretty but he kept it down and not made fun of me i still
50	grandpa tips it up again but the father pushes it back down and sets the boy on the seat next to his grandpa the grandpa turns off the lantern and folds his arms as the old	she never let me go and i just kept saying no she said no i did this i mean it was like the worst thing to have	told them to leave but the youngest one just kept saying no they had no money he was on a bus to get to the next	had the best friends at school but my parents didn't like it anymore so we just went on with our lives my mom and dad
60	man and his burly son both sit with their arms crossed the boy takes notice and folds his arms as well the burly man wipes his nose	happen to me my brother got drunk and killed himself my parents were in tears my sister and i cried and my dad stayed quiet as	stop and that he had been caught doing something i had done in my life i just smiled and said hi to him as i passed and	didn't really agree with each other and it wasn't a happy situation at all my brother was very angry he started screaming at me
70	the boy does the same he watches his grandpa twist his finger in his ear he mimics him	if to comfort me he tried to hold back but my brother had his hand on my shoulder he squeezed hard i cried harder then i just went	i got a hug in return i remember my mother crying a little and her hand rubbing my back and the next moment she was	i yelled at him and i hit him with my hand the other one went through my face i heard a crack and my vision started to
80	as a huge bright moon rises over the watery horizon the wide eyed boy's jaw drops the rippling waters around the rowboat	to sleep i was in a dark room in an abandoned factory where i knew nothing but the shadows it was a few hours later and	in a coma the hospital was a few miles from where i lived in the state that was so horrible it was almost	fade as the first light of dawn showed me a blurry view of a city that was far too bright for the sun i realized that i had
90	reflect the massive orb's glow the father hands the boy an anchor then opens a compartment the boy goes to drop the anchor his grandpa gestures for him to wait the	the building was dark and cold i got my laptop out and set it up to show her that i was typing it and when she asked how	a ghost town after the fire we were out of gas and i got my friend to help me load my truck he said to do it right away so he	traveled for hours to the airport and i was very hungry i went inside to grab something and the manager said i need to take the phone back to my seat he explained that we had
100	burly man lifts a long ladder from the compartment the boy watches the seemingly endless rungs pass by his father turns to him he gestures to head up	it was i explained how she could see the page from a computer that was not there before i left her office and said good luck to	took off the second time i had to lift it i got it about feet up and he grabbed it and pulled me up after him so	to stop in front of the theater so the car would park right next to it we then sat down and talked about this girl we
110	his grandpa also gestures for the boy to go on the boy slings the anchor over his shoulder ties its rope around his chest then heads up the ladder about	her she asked me to wait outside i took my hat off and held it under my arm so as not to fall and fell i felt	he could get me out of the water he held my hand while i walked around and then he helped me to my car which i had driven	both liked but she wasn't interested i decided to make up some excuse and go get her in a hotel room so that we could talk about
120	eight feet up he stops and looks back at the men the boy continues on the length of the anchor's rope	like the most beautiful girl on earth and my best friend was right behind me i could tell he was excited about the challenge	to the airport without him my best friend and i were riding shotgun i asked her how she was doing i didn't really care about her health as i was	what happened last night or how it was a mistake to say what we did and how we felt i have always been the person in my

Time (s)	Description ("La Luna")	S1 prediction	S2 prediction	S3 prediction
130	trailing behind him almost at the top he glances over his shoulder the giant moon hovers above still far out of reach as the boy clings to the top of the ladder	of seeing a new film he had no idea how the movie would be based on the people who actually did it i was going to watch it but	driving through the neighborhood and saw a man standing on a fence that was probably a little higher than a person should be i started to walk past	family that i feel close to when we were young and i never thought it would end up with us in a relationship and then he got cancer
140	his legs float up behind him he lets go to grab his hat then paws at the air as the moon's gravitational pull sends him crashing into its star covered surface	then i got sick and went to the hospital because my blood pressure was off my hand was hanging down my side of the bed and it	it and just before it went under my feet a strange sensation like i was going into the bottom of the ocean but in a	and it was like a knife in his chest and he went into the hospital and the next thing i remember was seeing the sky was blue and
150	as the boy sits upside down our view rotates around him so that he's right side up he finds himself surrounded by chunky five pointed stars which blanket	was raining outside the window i couldn't see the sun and the trees in the distance were brown and green it was so strange to	more solid form than the other times i went through this and the fact that i have had these thoughts in the past are very important i don't have	white and everything was quiet it felt like i had been there forever i could barely hear myself think the music was loud i thought it would
160	the moon's surface he looks around at several craters each filled with the glowing stars he looks down at the distant rowboat	be outside the forest at night in a place that had so much electricity and the rain in the morning i found out that	any proof that these people are guilty or even a reasonable doubt as to whether these are real or not but they were in my hometown and the state	be the most depressing song ever to play a single note for any reason that could possibly affect your day so i got to it
170	his father ties the end of the rope to the boat the boy takes the anchor and hooks it to the nearest crater with the rowboat	we had to leave and my dad went back to work my mother told me to take a look at it and it was in the attic	was looking for them so i said yes and they asked for the money back so we agreed that they could use it for something else so they got in	i asked for my phone and he said i need it he went to his car and started digging around the back of it and eventually he found a knife and cut his
180	anchored to the moon the burly man starts up the ladder the boy sees a shooting star which crash lands on the moon's surface	we moved it over to our house to keep it from falling onto our property and my parents got to it while my mom was in the car i	and we put them on the boat the pilot and i get on and they are gone i hear a crash and see a	way into the trunk and we all jumped in after him and the car got stuck he was not moving fast at all we were driving through the desert at
190	he hurries over to the new star as he taps it a brilliant flash ripples across its glowing outer shell he reaches to pick it	saw a red light at a gas station about miles away i could have just been imagining it it was so quick and so cold it felt like a	cloud of dust that seems to have formed on the ground and a bit of dirt in the air when you say	am when the first sign of a civilization we had seen was the sun rising or sunset at some point
200	up he leaves the fallen star and joins the men who trudge across the moon his father opens a shed and wheels out a bucket of various tools	hundred years later i found the remains of the girl and we were back on the street where we met up again at the grocery store to get some	it it is the sound of something that you are not hearing the noise of someone else coming to your aid this is what we do we	but i couldn't believe i had to go see this i went into my parents room and they had a bunch of stuff they were packing up and put
210	as the grandpa uses a besom broom to sweep up the stars the father grabs a push broom the boy reaches for a tool the boy	of the stuff to eat and she would bring a bottle of wine to drink with us and make a point of being polite about it we all	get people into hospitals and we have them take their drugs for a month they will not give them up i have a friend that does this and he says no but i	in a garbage bag with a few other items for storage in the trunk i didn't want to take anything i was like so why not put a
220	hops down from the bucket and his father gives him a demonstration he twirls his push broom and offers it to the boy the grandpa	did it but i had to put my hand over hers and squeeze gently so i could say a little bit of this in her ear my fingers are just	can't wait to get it in my hands he said well just hold it down while i do it then he told me to grab his belt loops	book on my desk and not use my computer if you need to write or make notes don't forget that you are supposed to do
230	gives a demonstration of his own then offers his besom broom as his elders squabble the boy notices the besom broom's	as long as hers and i don't mind that i'm the bigger man she goes with it i say thanks i love your girl but i think you should	and then pull on him with one hand then my other he was pretty confused i tried to help but he kept backing away then he	both in one class but you must do the other and that is your choice not hers she doesn't understand and neither should you she just has a different perspective
240	similarity to his grandpa's beard and how the push broom looks like his father's mustache the boy's eyes widen the star littered ground rumbles	leave her be my friend but not too much if you're dating her just because of what happened then i have a question for you when she	said oh and you just gave me a chance to see your tattoo the only thing i saw was your face but then the lights	than you because she sees your flaws as her own i mean look at her face now i was at that party when we got the
250	as a giant star comes crashing down from the night sky the trio dives in a star filled crater the boy peeks out first followed by his father and grandpa	was with me we had sex at a local gas station the day after we left her place it was late and the night before	came on and the room went dark and i woke up and everything was so weird i could have been dead and my mind	call that someone had died in the night the cops and i were out the front door to find an older couple walking the streets at

Time (s)	Description ("La Luna")	S1 prediction	S2 prediction	S3 prediction
260	the giant star stands before them one of its points stuck in the ground now the boy watches his grandpa try to pry the	was still pretty cold so the drive back to the hotel was quite a shock the night before was not exactly the best time to	was still processing the events and the feelings of having been a victim of such a terrible disease the fact that i had a medical issue made it almost impossible	about pm we had been watching the show and heard the same thing i thought what the hell why would i hear it when they were acting
270	star out of the ground with his broomstick as his father tries to push it over the boy walks up to the giant star	be having an actual conversation with someone about how they had a problem they were all too shocked to respond i was not really worried	to sleep at night for days and i have to fight with my mom for food and shelter she tells me to stay out of trouble i decide to go into	out how many times did they try to take my laptop and my car and beat me up i just thought the best way to make me believe in god was to talk
280	he knocks on its surface and a brilliant wave rises from the point of contact the boy hurries off and grabs his own tool from the bucket	but it was very close to my face and i could see a line of blood running down it i couldn't believe that this was happening so	the bathroom and i just start banging the wall so hard i hear it crack a few times it is a pretty big sound i think about	to a religious person about it and pray it out of them as soon as you hear the prayer and go to sleep and think about what the
290	returning to the star he stops and turns his hat backwards	i started walking over to the pool area i looked around for something to grab and nothing i went back and asked what he was doing then he	the noise in the background i get up to check it out i do this every night at my place so i can take my time with it i find	hell happened last night i went to my bedroom to grab my jacket and get ready for work when i turned to walk back to the kitchen
300	the men notice the boy climbing to the top of the giant star the boy reaches the uppermost point and feels the star's smooth surface he inches up a little more and takes	came up behind me and i was facing the window in a blind spot he grabbed my head and squeezed my neck i think i broke it in half	my wife on her back and i lean over her body i want to look into her eyes as i feel the pressure of the knife as she cuts	i saw the door to my parents bedroom was slightly open i had a strong sense of smell so i pushed my nose into the air
310	out his hammer and taps the tip from the top to bottom the giant star bursts into hundreds of smaller stars and the mens' eyes grow wide in	and he took my left ear and cut off the blood flow i was terrified of that for the longest time so i sat there	my balls off i take off the pants and her eyes go wide at the sight of them she is still in a	and it immediately turned a bright orange and i had to look away the color was red the guy was crying and it was all
320	slow motion the stars gently fall the smiling boy among them the burly man takes off his cap the stars collapse in a pile the	bleeding in the snow and praying and hoping to god that someone would hear my prayers for a long time and be saved it was a	very shocked state and is about to collapse with tears of fear she hears a voice and stops crying as the man says is	over the floor we were in shock the whole time and i could barely move my mom was in tears she was like wow he looks really scared
330	boy emerges from the heap later the boy uses a metal rake to clean up the stars as the men use their brooms the trio	big mistake i should have just said god bless you i thought but the other guy had to take his shot and he hit his head	it you i know you it is i said yes but my family didn't get married yet so my dad was taking care of me so	she said oh no he was so sad but she got a big hug and she was a huge fan of his and his band he
340	pushes the stars from right to left revealing more and more of the moon's bare surface back on the rowboat the burly man yanks down the anchor it drops in the water	and his friends were all like wow what happened here and so the story of how i killed myself is something i want to share i had to drive my father back	he had the money and i was paying him back in a sense it was just the way things worked we both got to our seats	also has a ton of other stuff on him but this is just another big thing to add to this guy i was walking out of the parking
350	and he reels it in as the grandpa pats the boy on the back the father pats him on the head the men trade a quarrelsome look then relax	to his apartment and put him in bed i have since changed my mind and am going to have my son sleep with his aunt and uncle to	and he pulled me to the side and whispered i really like your hair this is so good you should try it out for a while i'm	lot to go home with my friend and he was a cop and was like man i love you dude and we all just stayed there and then
360	we glimpse the trio's rowboat from a distance in the starry sky above them we find a crescent moon			

Time (s)	Description ("Presto")	S1 prediction	S2 prediction	S3 prediction
0	a tuxedoed magician beneath it a carrot lies on a dressing table from a nearby cage a white			
10	rabbit reaches for it he looks at his stomach he reaches again for the carrot which lies just beyond his grasp the rabbit furiously jumps up and	he had to put his hand over my mouth i didn't scream or struggle so he dragged me away and we	he was on the internet i could only see his face in profile but his eyes were a light blue and they were	we were sitting there with my hand on her leg and the car was rocking back and forth i could barely get in
20	down the magician enters the room chewing and wiping his mouth he eyes a pocket watch he locks the door and steps past the rabbit	went home my dad and his buddies were laughing and having a great time with all of us we got up and said good	just watching me he then took off his hat and stuck it in his pocket and told me to go to the	and she was going to throw up i took off my jacket and started rubbing my face and hands then i got a bit tired and
30	to a set of drawers opening the bottom one he keys into a hidden lock a compartment opens revealing a top hat and a purple wizard's hat the magician sets the top hat aside	luck we left the bar and the girls stayed behind with our drinks for a couple of hours to get my head on straight	back room and start looking at all the tools in the cabinet there are several different sizes and colors and all of them are very	walked back to the kitchen i noticed a big piece of paper in the front pocket of the old black and white
40	he blows into the purple hat and dust billows from the top hat as he sticks a hankey in the wizard's hat his hand pops out the top hat the magician uncages the rabbit who reaches	and after i got some of the adrenaline in i had a good laugh with a few other guys about how we could tell	interesting i have a box that was made with a piece of string i used to tie it to a chair for fun at home and when my mother finally realized	one the size of my palm with a few holes in the sides to show how to work it up in my hand when the teacher asks
50	for the carrot but gets carried past it presto sets the rabbit on the table's other end the rabbit heads for the carrot presto repeatedly pulls him back and sets the wizard's hat on the rabbit's	when our turn came i said okay and i grabbed his arm to keep him from taking off i got him to the car and started to drive it he didn't	what was happening she pulled me out and i was a little more prepared for her than she was i grabbed my friend who was trying to be	me to go and sit next to her she does not get up to help me i stand there and she tries to hold me down and i fight her off
60	head presto reaches into the top hat and pulls the rabbit out he offers the carrot to his pet without feeding him the magician	say anything or try to pull away but i did and he said do not push it and i just let go he then moved on to another guy but he	the role model and gave her some encouragement so that she could pull it off i took a shot with her and told her to keep it down when the song	i can't do it i'm just like you you want me to hit her so you can make sure it's not happening and then you say well i'll be watching this video
70	hurriedly sets the rabbit on a table backstage the rabbit wears the wizard's hat in the wings as presto walks on stage the magician seems to produce his top hat from thin air he shows	had no clue i was still hanging around my old high school and it was very crowded we walked up to the stage and started singing the	ended we left the club and were walking around the city at a nice clip we started talking about how cool it is and how it really	for you when the cops show up so that you know the whole story what happened after that is very simple and pretty basic you
80	the inside of the hat then reaches in frowning he spies the rabbit in the wings holding the wizard's hat aside so that the magician's hand gropes nothing presto beckons with two	first song we could imagine in our minds and the band played on a little bit of the same theme that we would hear from the people who had	just happens that you know each other and have been in love for years but how we didn't go to the same school when i was my mom said i	have a very vivid imagination and can tell what the real world looks like without a doubt i know that if i can't be with him
90	nods the rabbit shakes his head and mimes eating the magician's hand grabs for the rabbit but the bunny bangs his hand on the table as presto	been singing that day the reason it is important to write something about what the song means is that they can hear it from miles away so if they are	should be a doctor because of her diagnosis i didn't understand and asked why not because she had cancer it took about hours to explain i was a	i don't want to be he will never love me i can not do this i'm sorry he said the same thing over and over he says you must leave him i left
100	stalks towards the wings the rabbit fearfully puts on the wizard hat on stage presto reaches into the top hat a mousetrap dangles from his fingers the rabbit	watching you you are not being followed in this case so i suggest you wait until the next day and then inform your family i was told i would be	nurse and my family was there for years before i went into a coma after being a resident of the hospital for a while and	him there the entire night i stayed awake thinking he would be back soon and that he had just had a horrible day he was drunk and
110	mimes eating then opens wide hungrily before the wizard hat presto pitches an egg into the top hat the rabbit dodges the egg and catches it in the wizard hat sending it back to	attending a funeral of a woman i had just met but that she was dying to be buried the only thing she did was take off her clothes and	having a bad day i was just there to get her the medication i gave her but i also wanted to give her a chance to heal from	it wasn't good for him i know this is the best thing for you because i have seen it before the cancer ate the liver and left

Time (s)	Description ("Presto")	S1 prediction	S2 prediction	S3 prediction
120	splat in presto's eye now the magician turns the carrot into a flower the unamused rabbit holds the wizard hat to an air duct and presto's head gets sucked into	give him a blow job i went in for a hug and to my surprise he was pretty happy with it but i felt bad so i gave it back	her childhood in order to have a happy life she said she could do this alone i understood and gave her my blessing when i saw her face as	the body and it wasn't good to say the least and he was able to do it but he didn't get it and the other guy
130	the top hat as the magician frees himself the rabbit points to his open mouth presto grabs for him so the rabbit slams his fingers in a drawer and pulls props from presto's	he had his own copy of the original and was just a little bit upset and angry he said the thing to do is get rid of	the pain ripped through her body she was like i could see her mind screaming at me i just want you to stop she had her arms	got caught by the cops and his face was black and blue i remember the next time he tried to take my picture i got him in the leg
140	sleeve as the magician charges the rabbit holds up presto's hand the magician's own fingers poke him in the eyes presto reaches off stage into the wizard hat his hand rises from the	it i went to the local church to pray for my friends who were being abused by my ex in my head i was crying	around the guy i had just saved her from he had been at my place that whole time and had seen my girlfriend on the floor and i was	and then on my computer i had to stop him because my friend had his hands on his pants and i was a little awkward with
150	top hat and yanks off his own pants the rabbit unhooks a ladder on a wall it falls into the wizard hat pops up through the top hat and hits the magician in the crotch	when i read that and i told him so i got on the internet to try to find out why i was there and how	just watching the show that was the best part i got to sleep in the same bed and not be on the couch which was not	him and he was embarrassed about it and was looking around at the room we were in the middle of when it hit me how far it
160	presto eyes the long ladder then aims his end at the rabbit who dodges the ladder hits a door but continues coming out of the top hat forcing presto across the stage his chin	the system worked i found that if i wasn't there i would have to leave it to my wife or myself and be in a state of depression for	that long ago the problem is that he has to move in with me i think that if i take him over the threshold of a relationship it	was to the bottom and how much of an advantage it would be to climb up and over a hill or two before landing in the back of a truck
170	hitting rung after rung presto lands on his head he stands breaks off a piece of the ladder and shows the carrot the rabbit beams presto covers the carrot with a cloth	years to come because i felt so bad for myself i did some drugs and it wasn't enough i wanted more so i was going to use weed but i	will just be one big happy family i am a pretty average guy i like to look good but i don't always wear the right clothes	or train i think it is important that i describe myself as an experienced person that is what i want to do i will do this i have no
180	he clubs the carrot then reaches into the top hat the rabbit aims the wizard hat at a power socket electrocuted in his boxer shorts	had to have something i felt that i needed to feel good about myself i also have an urge to see a doctor i guess	i also have a few flaws and i'm not going to say i was lazy or stupid or anything but i didn't work in the restaurant because it	interest in doing drugs i don't smoke weed but i would never use it or take it i was going to have a fight with my wife
190	presto stomps a foot two orchestra members strike up a banjo and washboard the rabbit pulls presto's finger from the socket and the top hat pops off presto's hand the magician	that was a pretty long time ago but i remember being scared every single day and trying to fight back the panic that comes	was an open mic night so the staff had no reason to show up or the food was going bad i was told i could leave after minutes	and get into an argument about what to wear she was a big fan of the dress code and that was enough to make her start to
200	drops then chases the rabbit who hides under a table behind the curtain presto reaches under the table cloth and fails to see his hand come out through the top hat presto pulls a peg	with this kind of fear but it doesn't last i end up leaving her alone at work and walking out to meet with the guy at his office when	of being called an idiot and that they didn't care i left in a rage i was sure they would be watching me walk down the street i knew the person	sweat and not a good sign i couldn't wait to get home i went out the back and i ran to the bus stop where my
210	holding a rope to a sandbag the rising rope yanks presto upward by his ankle the curtains part and a spotlight shows him dangling	i get there and realize i didn't have his cell number i start walking home to find the cops standing on the sidewalk the officer says this	who was behind me as it was a little way from the school so i headed off the road to see a movie the theater was not far away and	girlfriend had parked i was only feet from her car when i noticed the front door was wide open the police had been there so i was thinking
220	the rabbit skips now the rope unravels from presto's ankle and he plummets along with large cutouts of stars and a moon the rabbit gapes as the moon hits some lights	is your friend who ran into the street and asked for directions to the hospital then he runs into a traffic light and the police car gets	i was so excited that i took my dog and ran around the corner and into a large tree that was on fire and a couple	my friends were safe i had to run over there to help them the car was about to hit them when they were going to crash into a tree
230	snapping a rope and dropping a piano the props and piano plummet after presto the annoyed rabbit reaches through the hats and pulls his owner through the top hat as the props and piano	a flat tire and is unable to pull over i know that if i let her drive she will hit the gas and then run her car over	of people got hurt when they fell i was there to protect her so i jumped into the water and pulled her out and put her down my friends	they didn't get hurt i saw it coming and tried to save them by using my momentum i hit them and they all flew in one direction then another

Time (s)	Description ("Presto")	S1 prediction	S2 prediction	S3 prediction
240	crash presto pops from the wizard hat and freezes wide eyed the audience filling the concert hall gives a standing ovation the magician raises both arms and	me as well and we both die that was a very pretty scene the entire time the police had to ask me to move my car	and i swam away and they all laughed it was the best party we have ever had so much fun and everyone was great	then it was a full on fight the entire thing was happening in slow motion i could see her face i was shocked
250	grins the rabbit sulks off noticing presto grabs the top hat the rabbit turns back presto takes the cloth from the table revealing the carrot	i was like oh yeah that was me and i said no thanks officer i am just leaving i told him no i will take this one i	to us so i said oh man look i need a little more i asked so you know what and i told him yeah and	but she looked away and said oh i forgot something she handed me the bottle and i took it and put it back on my chest
260	the rabbit pops up through the top hat and joyfully eats it the magician offers his arm and the rabbit perches on it they bow and the image turns into the magician's poster	was only and had not gotten the job but it	he said he wanted me to put you in charge of	to let my heart calm down and then i was



Time (s)	Description (“Partly Cloudy”)	S1 prediction	S2 prediction	S3 prediction
0	partly cloudy dozens of slender storks fly past carrying heavy white bundles from their long beaks one lands at a home's open window and sets down its bundle revealing a			
10	baby another stork delivers a bundle on a doorstep it's two kittens	she would go out with people from other groups and meet guys she liked one of her friends got on her back and i sat	we used to play together i would walk up to my locker and drop something on the floor and then pick up the second bag and	i was on the bus and a woman came on with a toddler and the father was with them the
20	nearly a third stork leaves two puppies by a doghouse it takes flight again joining the rest of the flock the birds flap their wide graceful wings as they disappear into the clouds	her up on a park bench i knew she was drunk enough to be in a state of mind that would not be so much of a problem as a reaction	the third one and walk around the apartment the other three of us are playing the same game we have always been good friends and the only	mother was just a nurse and a doctor who was out of town in a week or so to make sure we didn't die and to tell
30	later they emerge high above the ground each stork approaches its own fluffy cloud as one lands its cloud smiles and presents a new bundle	to the reality that you are experiencing in the past the things that happened are really hard to understand or accept especially after reading this story my brother	reason we were there at this time is because the school is so large i remember thinking that the kids were so stupid to even ask me	me the best way to deal with that was to do nothing in the meantime we were working on this thing in my bedroom and my mother was standing next to
40	the others continue to land on their own pink clouds one cloud molds a kitten and zaps it with lightning bringing it to	and i went to the store with him and a few others and we found a table that was open we took off our shoes and started	out or that i was so nice to them because i knew that if they had to have their lives ripped from them that they	us we both looked up and she was in the process of removing her blouse and a bunch of buttons had popped and the
50	life it grooms itself another cloud creates a puppy the cloud makes a bone and the doggy shakes it in its	to play our guitars and then my sister grabbed a bottle of water and gave me one too so i had to put my feet up and	could have theirs cut from their hearts and replaced by the same pain and suffering the child went to school and she got married and had two	material had torn when she was a teenager and then again after she had taken a pregnancy test that day and after her and her father
60	jaws a cloud makes a baby human the cloud makes a football it puts a helmet on the	drink from her hand when she got it in her mouth she would just pull out another and then give it to you again and again i	sons the one in the picture had his hand on the baby she didn't want him to touch it so he would hold it a little bit then put it in	got to know each other i had her say my name in my ear i was told to take off my hat and then put it back on so i
70	baby the cloud takes away the helmet and wraps up the child in a bundle below the laughing clouds floats another lonely looking cloud he rolls	had to leave it there until the day before the trial when it was all over the whole town was so scared they had no	his pocket i went home and said no more this was the most beautiful night and it was my birthday and i was really depressed because i felt	could continue my work the next day i was there to help the other two customers the store was so busy that it wasn't too difficult to
80	a piece of himself like dough adds four legs and zaps it with lightning creating a baby alligator it snaps its jaws the cloud picks it up and wags a scolding finger	idea how to act on the news and even tried to put on an accent they would call the police and then just give me the finger	so bad about what i did i decided i would get some good grades i didn't have any problems with them and they were nice enough to not hurt me	find a chair with a bit of a push and pull it over and put a knee on it and you are like hey don't touch me it's
90	which the alligator bites off the finger grows back an out of breath stork flies over and lands on the cloud	and laugh it off i didn't feel threatened at all but the second my dad got a ticket for leaving his house for the weekend he	so i kept them i think my first experience with these kids was when my mom was visiting the hospital and i was helping her out she	too tight and i can barely breathe you want to know what i got at this point my brother was at my house for the last time
100	the stork salutes the cloud gives it a noogie the stork playfully pets its face with its beak then motions for him to hand over the	called me to ask what happened my brother and i had no idea and he was crying so i said oh i forgot i left a message and she told me she	was very excited about it and gave me the hug of life we talked about everything i said she asked if i could show her around town i told	i had a good laugh about this because i thought he was a nice guy i also said something like if you know this is what he
110	baby the cloud holds out the alligator it chomps on the stork's head the cloud yanks the alligator off and wraps it in a bundle	wouldn't be coming home tonight and i should just hang up on her and try to be nice she said i can't take her back and	her no i wasn't allowed to she started screaming and hitting me so hard it left a huge scar i went to her	is thinking i am going to hit him so hard he can hear my skull crunch and his face is completely red i tell him i can't take
120	with its beak the stork holds it out far in front of its body and flies off	she was pissed that i couldn't because of what happened at work and it was a lot of pressure from the government and the community	house and she was asleep and i was worried that i had just ruined a perfect evening for my best friend	him in the car we leave and the guy starts following us i have a hard time controlling my laughter as i drive but it ends when we

Time (s)	Description ("Partly Cloudy")	S1 prediction	S2 prediction	S3 prediction
130	later the cloud fashions another baby the out of breath stork flies up as it salutes a bunch of feathers drop from its scrawny wing	to keep a civil order on the streets after the first year or so when i got caught smoking weed again i told him that it would ruin my life he	the next morning we had a plan to get a car in and out of town after i got in i said to my dad i have an idea of how to	get to a local restaurant and i'm ordered a steak and some fries my stomach is killing me i ask him to grab the check i know
140	the cloud brings his sculpture to life a baby ram butts the stork with its horns knocking the wind out of the bird the cloud picks up the young	was pretty upset but we made a deal to avoid going back there he went to his father who had a very abusive relationship and a	do this i thought this would be easy to get off the ground by going down and running like a crazy person at least this was	what this means and he goes for it i turn around and am running right into his back i think it's the most disgusting thing ever as my
150	goat the stork looks up at a puppy running around another cloud the doggy gets some of the cloud stuck on its face and	lot of family problems to the point that my mom was at his side and his brother was in the kitchen drinking tea with him my dad said to	true in the movies and on tv where people are chasing and beating each other for sport or money or whatever but this guy didn't care that the other	friends and i are all in the kitchen having dinner with our families and all the people that we love in our lives my dad says
160	sneezes it happily licks its stork the lonely cloud frowns at his bundled baby ram his stork notices and sheepishly stops laughing	the other two kids what you doing here i didn't have time to reply i was so sorry i got here so fast so i just started	kids were looking at him funny he was like yeah i know and i'm not offended by this so i asked if they could stop him from hitting me i	this is my life and he doesn't need me anymore i look back to him and tell him no but i can't go to jail so i start running up the
170	the cloud places the bundle into its beak and it butts the bird repeatedly as it flies off later the stork returns the cloud turns to face it with a new	running back and forth through the city and up the hill towards the main road in the morning we decided to get a drink and i noticed a	got him into the hospital and the paramedics were there hours later the same day i was finally able to see him again it was a small	hill the last thing i remember before falling asleep was being in the hospital after an episode of the night before the doctor finally
180	sculpted baby the stork covers then grabs it with its wings just as the cloud brings it to life it's a prickly porcupine the stork	new sign with a picture of a naked guy with his hands tied behind him it read do not touch me in the future if you want	white box i didn't recognize the name on it and it had been broken in half so i took it in the front door and let it cool off	found out that it was a heart attack and she was having trouble breathing and getting her lungs pumped and in and out and everything she had on
190	flings it from wing to wing playing hot potato with it with each toss the bird gets more and more quills stuck in its feathers the cloud takes the porcupine and bundles it up the baby's	to leave with a few pounds in cash it should be no big deal just put in an hour or so and walk home on a monday	with the water and put it back together so it was a neat trick but i still ended up in stitches a week later i had the scar	her i could barely stand i had to be on my back for at least minutes in the hospital waiting room for about an hour after my
200	needle sharp quills poke out of the cloth the bird carefully takes it and flies off now the stork returns with a bunch of quills poking out of its head like an afro the	morning before classes start i was just going through some stuff and it was about a quarter of a page long and the paper was almost worn away i put	and it looked like it had been chewed off my lip from where he ripped it open he pulled my teeth and spit me out	surgery i was told my arm had broken in half and the skin was hanging off of my elbow and it would be ok to put my hand on it i have
210	cloud yanks them out accidentally plucking feathers along with them he hugs the stork then shows a cloudy baby shark the stork flutters backward the	it down and said ok what i do now is it will work it was then that i noticed that there were three little girls and their mother had	he then said this is where i learned this was the wrong place i was sitting at a table with about a dozen people that had	to get this out now or it could just be a random guy in the park or a group of people that have no problem being nice to
220	bird sees a cute flock of chicks bouncing around another cloud the lonely cloud holds out the molded baby shark his stork flies off to another cloud glowing pink with sunlight	left them for me and i thought well i can't stay there so i drove the bus and eventually found myself on the highway heading back towards the city	to know what happened and that my girlfriend was dead or worse i was the first to leave my apartment and walk to the other side of	the homeless man or whatever i didn't want to be there to start with and i certainly couldn't go back home and face the people of my town and say
230	the lonely cloud crushes the unfinished baby shark	i had just passed by and my buddy was right behind me so he was really freaking out and was running a mile per	town she was my only option to get help from her and i didn't have a choice i started to run i was in a fairly deep hole	hey this guy is my friend and he made a bad decision i was furious i started yelling and punching the walls of the
240	as he folds his arms and mopes lightning strikes downward from his base he sees the pink cloud giving his	hour down a highway so fast that it was impossible to tell which road the driver was on but he did not have a	with a very low chance of being shot down there was a lot of confusion and i remember seeing a bunch of cops and then	building the only way to make any sense of what happened was by telling people that he had no clue and he wasn't a cop
250	stork a bundle the lonely cloud turns away from them he starts to	clue that his friend was coming home drunk or high from all the beer i was getting up there i heard the	nothing i thought was normal it was like a dream i could hear the sirens coming and my brother screaming in terror as my mom and	but he knew that i was going to jail he started screaming and running away from the car when he turned around to

Time (s)	Description (“Partly Cloudy”)	S1 prediction	S2 prediction	S3 prediction
260	rain a feather floats past his bulbous nose he turns to find his stork flying down to him the bird	car and looked up and saw a police officer i knew that i had seen before he told me that he would take my picture for me he had	dad both went to get the gun in the end they took it to a friend who got it back and said we should put it in my pocket so he	see a guy coming from behind him i saw it the next day he came back with a new gun he said he wanted to give me a
270	opens up its bundle the stork takes out a set of football pads and a helmet and puts them on the bird demonstrates how hard its helmet is	a cell phone and a card for my photo and that we could have it for free but we both wanted it so much i said yeah sure	could use it on his motorcycle or whatever he had on him to do a bit of riding then he says oh i'm sorry he gets it from me and puts his	little extra protection so he could use his shotgun as a weapon so i put my gun away and just held onto it he was right there so we can
280	the cloud gives the stork a big bear hug the bird motions for him to hand over a baby the cloud brings a snakelike eel to life and	and he put it on the card i would have to wait until it was in the bag but he had a nice one that was pretty close to my	helmet on i did this for years and then i tell him he should take it off now it is about two months old i give him a cookie and he just lays	do this again i took his arm and said no but this time i put it behind me and pressed it up against my right knee then slowly and
290	it electrocutes the stork the bird forces a smile and the cloud pats it on the back	own but still too small	it out on my bed	with all my strength pulled

**Supplementary Table 3. Decoder predictions for perceived movies.** Language decoders were trained for each subject (using data collected during story perception) and then evaluated on single-trial BOLD fMRI responses recorded while that subject watched three animated short films from Pixar Animation Studios (“La Luna”, “Presto”, and “Partly Cloudy”) without sound. Reference transcripts—obtained from official audio descriptions for the visually impaired—are shown alongside the decoder predictions for each subject. Highlighted segments were significantly more similar to the reference words than expected by chance under the BERTScore metric ( $q(\text{FDR}) < 0.05$ , one-sided nonparametric test). The decoders generated language descriptions that capture the meaning of the perceived movies.

Time (s)	Actual stimulus	S1 prediction (cross-subject)	S2 prediction (cross-subject)	S3 prediction (cross-subject)
0	i reached over and secretly undid my seatbelt and when his foot hit the brake at the red light i flung open the door and i ran			
10	i had no shoes on i was crying i had no wallet but i was ok because i had my cigarettes	he had a girlfriend that was also a lesbian i told them to stay away and to stop texting each other i was only talking about the sex part so	he had a great time and that the date was perfect for them and he was totally in the right place to have sex i was a little	he was in my car at the time and was drunk as hell i didn't have insurance but my mom would have been in trouble if i had let my kids
20	and i didn't want any part of freedom if i didn't have my cigarettes when you live with someone who has a temper a very bad temper a	i would know they were together if i could just see them kissing on the beach i didn't even care they had a history of dating i never said	drunk and did not remember his name but it was his birthday so he got his present for christmas the first time ever so i know the rules	drive in that state if they had gone with the same style of car and had been given different choices the law of the land was
30	very very bad temper you learn to play around that you learn this time i'll play possum and next time i'll	anything but the moment he walked on the plane i had the urge to make him pay i made a comment about the man he had killed but	of engagement and i want to say something to him that he has been trying to break but it's not working the words are like i want	a big one in that there was no reason to have it the fact that we had no water was a sign of weakness i have no
40	just be real nice or i'll say yes to everything or you make yourself scarce or you run and this was one of the times when you just run and as	he just continued to laugh i think the point was to get you in trouble i am a big guy i can't have you coming out of my	to go to jail for life my only hope is that she doesn't say anything about the drugs in my case it doesn't look good at all	idea why he didn't just turn me in or at least i couldn't have told him what i was doing for sure and he was too busy telling
50	i was running i thought this was a great place to jump out because there were big lawns and there were cul de sacs and sometimes he would come after me and drive and yell stuff at me to get back in get back in	room i was raised in the house of the same name and i know the stories you can hear from there my mom would bring up a good point and then leave the	and the police are talking about how to stop it the next morning the cops are on the scene and we can hear the commotion that followed as we wake up	the story of the night i got mugged to notice i was in his car and the cops didn't follow me home i asked if he would stop and i saw that he
60	and i was like no i'm out of here this is great and i went and hid behind a cabana and he left and i had my cigarettes and uh i started to walk in this	discussion there was no argument she had and i was completely against it after that and it was very awkward for me because i couldn't get my head around	and decide to leave the house the paramedics arrive and start talking about the accident i think they were pretty cool and did some work but my friend had to have a	didn't i started walking in that direction i was a bit surprised but i also knew i couldn't just sit and wait i took a seat and i just
70	beautiful neighborhood it was ten thirty at night and it was silent and lovely and there was no sound except	it my family and i were going to spend the night together but it wasn't to do anything special and we went to a hotel to sleep	stretcher for a few days because the whole hospital had one and a half and he was pretty sure the nurses and doctors had some sort of disease and would need	started talking and then the door opened and we went and got her and the whole thing was awkward after that my dad and i
80	for sprinklers ch ch ch ch {ig} ch ch ch ch {ig} and i was enjoying myself	it was a typical one for the first time i got to be with her and i had to tell	a special room to live in my dad decided to get a job and take the opportunity to put himself out there i have always been	stayed there a little while and then he said to me you can do it now just keep on doing it and get it
90	and enjoying the absence of anger and enjoying these few hours i knew i'd have of freedom and just to perfect it i thought i'll have a smoke and	her how i felt i didn't have any experience but she was there and it helped that she knew me i had to get it out there in my life and	able to say no to other people and to my friends i never gave in to anything and was just going to take whatever i wanted i would spend hours at	done soon enough the time to do this is in the days ahead of me and my partner in crime but the idea of it is scary
100	then it occurred to me with horrifying speed i don't have a light just then as if in answer i see a figure up ahead	that meant i could talk about it in person but i did that with a few people and i got to go to school with one of them	home and it was all just to make her happy i got the job i was hoping for and that is all it took i started getting her	as hell if the police get involved i think i will be in danger from the cops after i leave i would suggest that you see a doctor i
110	who is that it's not him ok they don't have a dog who is that what uh what are they doing out on this suburban street and the person comes closer and i could see it's a woman	the teacher told us to do it at home i think they were all pissed i had just gotten a job and i was already looking at a year old baby girl	excited and then when i had her ready i pulled out and drove down the highway the other way we ended up coming up on her house i	am on vacation so if you have an issue you might consider telling someone who will listen the first time i talked to the doctor was i had a panic
120	and then i can see she has her hands in her face oh she's crying and then she sees me and she composes herself and she gets closer and i see she has no	so they wanted to see me as an adult and not the kid they were asking about i said yes and the two people were still talking to me about their	turned left onto her street and then i heard my name she said you have to go away and i did i got a text saying you	attack or something and had to have stitches in my arm when he checked i was going to die and i wanted to see my friends i went into

Time (s)	Actual stimulus	S1 prediction (cross-subject)	S2 prediction (cross-subject)	S3 prediction (cross-subject)
130	shoes on she has no shoes on and she's crying and she's out on the street street i recognize her though i've never met her and just as she passes me she	son they had to be a year old so i figured maybe my dad had gotten them to stop calling and just give me a raise if they were	are not welcome in my life and then my friend just said yeah you should have seen him after the fact i asked him to get	a panic but he kept saying i am a god he was so far gone he could have died i remember asking him where his children were and he said
140	says you got a cigarette and i say you got a light and she says damn i hope so and then sh first she digs into her cutoffs in the	going to have a child then i wanted to know now if you are still willing to get the baby in if so i was looking at the idea of	his license he told me he was already at it and i didn't know the car was under the hood he called and said he had a situation	they are with your daughter and that he could not be reached if she were to call i have no idea why the father wouldn't answer a
150	front nothing and then digs in the back and then she has this vest on that has fifty million little pockets on it and she's checking and checking and it's looking bad it's looking very bad	adopting a little girl or boy and not the guy and my mind is getting lost in the fantasy i think the real me is having trouble with it i	at the school that would not be handled at all with a phone and that i could not use it the kids at the time were not allowed to	phone i think he had an appointment and forgot to put his cell in my car i guess i was out of line for some reason and didn't notice because i
160	she digs back in the front again deep deep and she pulls out a pack of matches that had been laundered at least once ugh we open	mean my brain is trying to remember if the guy in the video is talking about how i look but i don't want to be too obvious i	play outside because they were so old my sister had her own rules to follow and was a lot more concerned about the kids and i was trying to	had to wait for it to pull out and i was really close to it but it wasn't fast enough the truck was too big for
170	it up and there is one match inside ok oh my god this takes on it's like nasa now we got to like oh how are we gonna do it ok and we we hunker down	think you should tell me your thoughts and feelings about it you know how to get through it without breaking down i mean how can i explain the pain	teach her some of mine and we were all working on getting a little closer we ended up just sitting together in a circle and i kept staring into her eyes	me so i got stuck with my friend and we just kept moving i guess the guy was bored with being the center of attention but we were doing things
180	we crouch on the ground and where's the wind coming from we're stopping i take out my cigarettes let's get the cigarettes ready oh my brand she says not surprising and	and how do i describe the way my heart broke as i read it and felt it break as my friends told me to and i did it	as i went from kissing to making out and then finally to holding her hand she let me do this for hours i think we both liked it and	to make the crowd stop i think we had to pull out of the line and let the police know the problem was with the cops and not
190	we both have our cigarettes at the ready she strikes once nothing she strikes again yes fire puff inhale mm sweet kiss of that cigarette	in front of everyone and that i would get a beating i was shocked by how good it felt i told my manager to take it easy	i didn't really get mad or anything after i took it out and started sucking it she made me go in and eat it so i went into the bathroom	us he got the message and just ignored it but i can't explain it he started hitting me again i just kept on punching him but then the
200	and we sit there and we're loving the nicotine and we both need this right now i can tell the night's been tough immediately we start to reminisce	i had a really bad day and he wasn't happy to hear about it and said to get to class he was in the middle of the	to vomit it up while she watched i was able to finish the meal and get it out of her system i have to say though that the conversation was	girl came and put a stop to it i went into a rage because i could feel that her life was being wasted i started talking to the police and asking questions they
210	about our thirty second relationship i didn't think that was gonna happen me neither oh man that was close oh i'm so lucky i saw you yeah then she	room when he stopped talking to us we got very close and i could smell him so i just took one step back and we had	fun i did not think the whole thing through and i felt pretty comfortable talking about it in person i thought i was being honest when i told	weren't allowed to answer i even had a video of it happening i was not a lawyer i just watched it and told my
220	surprises me by saying what was the fight about and i say wha what are they all about and she said i know what you mean she said was it a bad one and and i said	sex the night before he asked me out and i said yes we made it work i had been to many parties and was never afraid of them but she had just	my parents what had happened i didn't feel that the story was very long and i did tell them how the girl died i had to leave	story as a professional i have no idea how many of you are wondering why this was not discussed with us at all if this is true
230	you know like medium she said oh and we start to trade stories about our lives we're both from up north we're both kind of newish to	turned me down flat for no reason i tried to do it for a friend and he was in a bar at this point i had lost my job	that day because the police had found out my address and my story i ended up moving to another city that had the same problem with my	then why not talk about it at home i mean we are adults here i was going to a party but we don't have any alcohol there is a liquor store
240	the neighborhood this is in florida we both went to college not great colleges but man we graduated and i'm actually finding myself a little jealous of her because she has this really cool	and was looking to leave it because my parents were pretty strict about paying rent i was about to give up because of this i ended up with a	house as my parents the place i had a really hard time buying out but the other thing was that the landlord didn't let me use the basement my	across town and it is open for business at night it's like the middle of nowhere if you want to drink it's at this bar the whole time and they have a pool
250	job washing dogs she had horses back home and she really loves animals and she wants to be a vet and i'm like man you're halfway there	job that didn't allow for that and a lot of money and that i didn't like so i started a website which was open to	friends had a huge problem with my apartment but it wasn't that i couldn't move in or something my roommates were not exactly supportive but i could get	table or something i used to do in the evenings and i have this feeling that they are in my room now but not just on my

Time (s)	Actual stimulus	S1 prediction (cross-subject)	S2 prediction (cross-subject)	S3 prediction (cross-subject)
260	i'm a waitress at an ice cream parlor so um that's not i don't know where i want to be but i know it's not that and then it gets a little deeper {cg}	anyone and all my friends i got into i was actually going to do this a week or so after the school closed so i could see my	by on the couch and it wasn't really an issue and i would always take my friend who was going through something and come sit with him on the bus as	computer i can't see them on the internet and i am really scared to ask people if i should leave the store i look up the number
270	and we share some other stuff about what our lives are like things that i can't ever tell people at home this girl i can tell her the really ugly stuff and she	friend and then we had lunch and i asked my mom where the food was i think she knew since she told me she made it i was able to make	a guy who didn't get along with his fellow passengers who would try to give him space or something and he was probably in the minority so the plane took	and am about to say it's a little late i had a lot to do and then i heard my name and the whole thing came out as the best
280	still understands how it can still be pretty she understands like how nice he's gonna be when i get home and how sweet that'll be	the meal without crying i also remember the exact words i heard as i ate they said if you are not ready for the next step and have	off he had just lost his job and i knew he would be gone i had a few hours left i sat at his desk and took the	i could but the words were not enough for the person who got it all out the second i put the pieces together they
290	we are chain smoking off each other oh that's almost out come on and we go through this entire pack until it's gone and then i say you know what uh this is a little funny but you're gonna	a heart condition like you described then they can remove the tumor you mentioned and put the new one in place as the doctor said i guess i don't have that problem	first step i started crying he got a hug and then a kiss from me after a minute he let go and i went inside to make dinner	had a huge pile of money and they wanted it back so they cut off my hand and it was my turn to get it i didn't care
300	have to show me the way to get home because although i'm twenty three years old i don't have my driver's license yet and i just jumped out right when i needed to and she says well why don't you come back to my house and i'll give you	when i have to take it out on you and your family the reason i got out was to see someone else i was trying to avoid i don't	for them i was surprised that they had eaten all that i had done i told my parents i would do that and i left to go find him	i was scared because the other kids were screaming and i knew it would happen if i stayed in the room with my friends i eventually calmed them down and we
310	a ride i say ok great and we start walking and uh we get to this um lots of uh lights and uh the roads are getting	have a job so i just hung out and i got to know him well enough that i could have an opinion on everything and it wasn't like	he was there and the lights were on but he didn't see me i looked up the road to the bridge i had seen before and was very aware	talked it out then i got out of there i walked around my house a bit to check for messages then went to my mom to explain
320	wider and wider and there's more cars and i see um lots of stores you know laundromats and dollar stores and emergenciers and	i was in a social setting i knew he was there i saw him at work and in my classes and on a bus i was a few	of it now i didn't need to worry about traffic on this side of town so i walked my dog through the park i kept thinking about that time in	what had happened but i had to walk around and i could feel my head spinning i ended up in a park and there was a cop i don't know him
330	then we cross over us one and uh she leads me to some place and i think no but yes carl's efficiency	feet from him when i realized i couldn't take his seat and he would see me i took his place i had to do everything myself	the woods and how i felt like a stranger there and then i told her about the dream she thought she knew i was an angel	so he pulls up and says what happened there is a fire in your house that is spreading and there was an explosion at your place i told you i
340	apartments this girl lives there and it's horrible and it's lit up so bright just to illuminate the horribleness of it it's the kind of place where you drive your car right up and the door's	he was like what if i go to prison i could just kill myself i had a mental picture of him at that age i didn't like the	but i didn't feel like a ghost to her the other night i got in trouble with the law for being outside i had a cell phone on me	am going to be working at a gas station at night you didn't like the way the store looked and decided to sell something that wasn't there before had
350	right there and there's fifty million cigarette butts outside and there's like doors one through seven and you know behind every single door there's some horrible misery going on there's someone crying or drunk	idea of going to prison i thought of the other inmates as well i think of them as people that i don't like at all the idea of going	but the other kids had theirs on the table as well as some other things the teachers were just a bit weird about me and they told me	a nice window on the outside for customers to view the inside the front door is not an issue at all and i am not worried about security guards
360	or lonely or cruel and i think oh god she lives here how awful we go to the door door number four and she very very quietly	to prison and not having my dad be there was hard but i have to think about it i was so angry i would say a prayer and ask	to have fun in school and i did i got a job and the kids were fine with that i started spending time with them but then my mom went	and the like they are probably on vacation as they have all been told to be i go inside the store and order the same
370	keys in as soon as the door opens i hear the blare of television come out and on the blue light of the television the smoke of a hundred cigarettes in that little crack of light	for help the first day i walked in on the teacher yelling at the kids and i saw a picture of the school in a magazine i thought was	nuts i was already working late and i could feel her coming on to me i had to be honest my dad was in the room and we didn't speak	thing i said and then i went outside to get more and the customer was there i had to put my arm around her and she was just like

Time (s)	Actual stimulus	S1 prediction (cross-subject)	S2 prediction (cross-subject)	S3 prediction (cross-subject)
380	and i hear the man and he says where were you and she says never mind i'm back and he says you alright and she says yeah i'm alright	really cool i asked my mom how they had done it she said they just talked and then the doorbell rang she was out of it but was	until the girl and her father had left he said we should leave he told her i was going to find her and she started	what if i take her out to eat she then said if you don't i will never see her again i agreed with her i had
390	and then she turns to me and says you want a beer and he says who the fuck is that and she pulls me over and he sees me and he says oh hey i'm not a threat	pretty drunk i let her in i was the first to hear her crying so i called the cops and she was fine i don't think she realized the	crying i thought maybe i could help but she said i was a stranger and i should go get her she didn't know my name i got a	been thinking of giving it to her and saying no she wanted to have a birthday party but i was really depressed i told her i
400	just then he takes a drag of his cigarette a very hard hard drag you know the kind that makes the end of it really heat up hot hot hot and long and it's a little scary and	state of her hair and i had a hard time getting it all in there i told her the color was black but i could still see it as it	few texts and it was the first one that popped up i opened the second and i think i actually broke something in my back i guess	would try but she couldn't handle the weight and was too far gone to get it right it was a long road and we got stuck
410	i follow the cigarette down because i'm afraid of that head falling off and i'm surprised when i see in the crook of his arm a little boy sleeping	was now i explained that the light was green i think this was because i was going to take it down and there was a cop standing	i should add that i was trying to break the other arm in a very painful way by getting to know him better he was the guy who	on it i had to break the speed limit a lot to keep from hitting her because it was a little slow i tried to avoid the accident with the other cars i
420	a toddler and i think and just then the girl reaches underneath the bed and takes out a carton and she taps out the last s pack of cigarettes in there	behind the machine and he was really pissed i told him what happened and that the kid was trying to stop it so i put the battery in the car and we	helped me and i still have some issues with it and it really makes me wonder about some things my friend was doing while he was dating her so i	also had to put her down and i did this by the way she was getting her hair messed up i took her out and picked her up in the parking
430	and on the way up she kisses the little boy and then she kisses the man and the man says again you alright and she says yeah i'm just gonna go out and smoke with her and so	were both really upset i mean i was and she was i just said i'm sorry and started driving off we had no money or anything but she got	went to their place and just sat on the couch he came out and started talking about the future we were living in the apartment so he had the opportunity to take some	lot and brought her to my car the first time she said yes and we proceeded to kiss and talk about the whole thing we went to the
440	we go outside and sit amongst the cigarette butts and smoke and i say wow that's your little boy and she says yeah isn't he beautiful and i say yeah he is he is beautiful	a new car and i took my time getting to know her i was like wait she can drive you home but what about me i	of the photos from the internet with him to his friends who were getting out of school early and it was just like him and me he was an	same school but we didn't get to spend a lot of time together during this year my brother is now i mean really close friends
450	he's my light he keeps me going she says we finish our cigarettes she finishes her beer i don't have a beer cause i can't go home	had a ride to work on time and was able to take care of myself for about minutes in the day i had no	idiot i told my mom and he just cried for about minutes until i finally left him for him to get out of the house i knew he	and i can tell that he's very interested in being my boyfriend and that he feels comfortable with me being on the dating site but it's still awkward to
460	with beer on my breath and she goes inside to get the keys she takes too long in there getting the keys and i	pain in my hand i could do something about it and i got to my feet and walked towards him the only problem is he wasn't moving	was in pain because my phone rang i was worried i could no longer help him and the nurses would be all over me i went into the room	have sex with him as an older couple so i tell her to wait until after dinner to get ready because i'm gonna take a quick shower
470	think something must be wrong and she comes out and she says look i'm really sorry but um like we don't have any gas in the car it's already on e and he needs to get to work in the morning and um	so i made a mistake i asked if he needed help i had a little time left on the job but he would not hear of it i made	and said the patient was gone i couldn't see his face he was a man so i took a picture of him in his grave i didn't	i don't think it will happen soon because i can't remember what was wrong i didn't go to the doctor for my period i couldn't find one to tell
480	i you know i i'm gonna be walk to work as it is so what i did was though here look i drew out this map for you and you're really you're like a mile and a half from home and um if you walk three streets over you'll be back on that pretty street	some small talk and he responded in kind i have a few stories about that man and how i can't get out of his head but i feel like i'm still young enough	know why he died and i did not ask i thought about his face and how it looked as he passed from this life and this new one this was	me i was on birth control so i just asked the nurse where it was she said it's on the floor below you and i took that to mean it's in the hallway
490	and you just take that and you'll be fine and she also has wrapped up in toilet paper seven cigarettes for me a third of her pack i note and a new pack of	to remember my parents i want to say to my sister what was in that book so she can put it in a museum i was so excited to have	a great idea i decided to write my name as well as the title of the story to give people something to read i was	to your left i went to follow it with my eyes but my mouth was full of bread and i was too big for the sandwich i just kept

Time (s)	Actual stimulus	S1 prediction (cross-subject)	S2 prediction (cross-subject)	S3 prediction (cross-subject)
500	matches and she tells me good bye and that was great to meet you and how lucky and that was fun and you know let's be friends	it she brought me it and i got to play it out with her she had been very open to the idea of sex for years so i	in the hospital and it was an accident and i got to talk to a doctor but he had just taken his medication and was asleep in	saying you got me in trouble and the kid said yeah that was it we were both a little pissed but i just told
510	and i say yeah ok and i walk away but i kind of know we're not gonna be friends i might not ever see her again and i kind of	was a bit shocked she said yes i mean we didn't know that at the time and the whole thing just happened to me it	a coma i told him to go to hell i was there and i knew he was dead i took his place and when the doctors started telling me to do	him to stop and i would go see a therapist or something eventually he gave up on the whole idea and we did all that and now we
520	know i don't think she's ever going to be a vet and i cross and i walk away and maybe this would've seemed like a visit from my possible future and scary but it	is possible to lose touch with people because of it i can't believe my brain is playing the game i think if you start talking to someone about	something about his condition i was pretty shocked to realize that it was the cancer talking and the fact that i could see it on his face he also mentioned	are able to have sex at am in my office we have no problem with the time difference and that we both know what to expect of the
530	kind of does the opposite on the walk home i'm like man that was really grim over there and i'm going home now to my nice boyfriend	this it will be all over the school i know the kid and the teacher at least he is doing well i think they were friends before they	that his mom died recently i did not know this until my mother told me i am sorry my brother had to deal with her death but i can	job we get and it isn't always a happy one we don't talk about the work but it does mean that if we go out drinking and smoking it is all
540	and he is gonna be so extra happy to see me and we have a one bedroom apartment and we have two trees and there's a yard and we have this jar in	started doing things and i have seen them talking about getting together a lot i was once in a group of about people and one of them mentioned how he	still think of her and my dad are you okay with this i mean the other one was a big deal the way they treated me and all the kids	over the place for her that i don't know she has no friends i am in my room in the house and i think about what it will cost for the
550	the kitchen where there's like loose money that we can use for anything like we would never ever run out of gas and um i don't have a baby you know so i can leave whenever i want	wanted to see my tattoo and i didn't feel like talking about it with anyone except him i had to hide the scars and not tell him it was	they had in school but the last time they gave me money i was not happy they just ignored me and the food i ate i got	dog to eat and it comes up with me buying it for my daughter it is a big deal for me to take a job and i love her
560	i smoked all seven cigarettes on the way home and people who have never smoked cigarettes just think ick disgusting and poison	me in the hospital so my friends could get to know me i just cried all the time he didn't even have to touch my hand when he	a few bucks and it was enough to cover everything else i also bought the first two bottles of wine i was offered in the beginning	i get her out of my head and she seems fine as i think she might even like me after all she was always good with computers i thought this was
570	but unless you've had them and held them dear you don't know how great they can be and what friends and comfort and kinship they can bring	passed away i would take him and ride my bike home i had to do this in a hospital and he was a minor in an accident i	and it was great i didn't mind drinking them at first and then they became a real treat i just went with the flow a little bit and took the whole	great when she started using them and was so smart with them that i wanted to work on her programming and she was very helpful with it as i was
580	it took me a long time to quit that boyfriend and then to quit smoking and uh	told him to stop i was on a mission and i would not be delayed this time i did not say a word to the other soldiers at first	bottle with me as well as a small handful of the beer he said he could use the extra i was able to make at least and a	doing something like that she had been trying to do research and was also a good listener as well we had a few arguments about how she was using the right
590	sometimes i still miss the smoking	they seemed confused i had the	half or more to help me	to choose a boyfriend i would

**Supplementary Table 4. Cross-subject decoder predictions for a perceived story.** Surface-based methods were used to align training data across 7 subjects. Cross-subject decoders were trained for each subject using aligned data from the remaining 6 subjects, and then evaluated on single-trial BOLD fMRI responses recorded while that subject listened to the test story “Where There’s Smoke” by Jenifer Hixson from *The Moth Radio Hour*. The actual stimulus words are shown alongside the cross-subject decoder predictions for each subject. Highlighted segments were significantly more similar to the stimulus words than expected by chance under the BERTScore metric ( $q(\text{FDR}) < 0.05$ , one-sided nonparametric test). Cross-subject decoders performed barely above chance, suggesting that subject cooperation remains necessary for decoder training.