THE READING BRAIN PROJECT

Methods for Data Collection（L1 Adults）

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Methods for Data Collection (L1 Adults Data)[1]

1. Participants

Fifty-two right-handed native English speakers were recruited from Pennsylvania State Hershey Medical Center. The participants (24 men) were aged between 18 and 40 years (mean age ± SD = 22.85 ± 4.66 years). Eye-tracking data were missing for one participant during one fMRI run (see Note** of Table 1). Overview of recruitment data is presented in Table 1, and the number of participants who completed all behavioral tests is included in Table 2.

Table 1. Overview of L1 Adult Participant Recruitment

Task	**L1 Adults**
Behavioral tests	≤50*
Eye-tracking	52**
fMRI scanning	52
RBQ	50
Reading texts	52

Note: L1 Adults = monolingual English-speaking adults; RBQ = Reading Background Questionnaire (Follmer et al., 2018). *Number of participants for behavioral tests varied by test; see Table 2. **Participant ID #21 did not contain eye-tracking data for the 4th run of functional imaging (the GPS text). Thus, this run cannot be analyzed.

All participants were right-handed, had normal or corrected to normal vision and had no past or current history of mental or neurological disorders. The study was approved by the Pennsylvania State University Institutional Review Board (IRB) and was performed in accordance with the ethical standards described in the IRB. Written informed consent was obtained from all participants before they took part in the study.

[1] The data collected from L1 Adults are part of a larger project that also includes data from L1 Children, L2 PSU adults and L2 Beijing adults. This document only applies to the L1 Adults data.

Table 2. Number of L1 Adults Who Completed Behavioral Tasks

Behavioral test	Participants*
ANT	50
GSRT	50
LNS	47
PPVT	40
TOH	49
Raven's	50

Note. ANT = Attention Network Task; GSRT = Gray Silent Reading Task; LNS = Letter Number Sequencing; PPVT = Peabody Picture Vocabulary Test; Raven's = Raven's Progressive Matrices; TOH = Tower of Hanoi.
*See details in Appendix Tables B1-B5.

2. Procedure Overview

The study consisted of two sessions (see Figure 1 for the general procedure and Figure 2 for an overview of behavioral tests): MRI acquisition and behavioral tests, roughly one week apart. During the first session, following the scanning of structural (T1-weighted) and resting-state data, participants performed a reading task with simultaneous eye-tracking and fMRI scanning, and the session ended with a diffusion tensor imaging (DTI) scan. Participants then completed a Post-Scanning Questionnaire (modified from Diaz et al., 2014), which assessed their experience and feelings (e.g. boredom, sleepiness) during the MR scan. The second session consisted of only behavioral tests, including six standardized tests: the Attention Network Test (ANT), Gray's Silent Reading Test (GSRT), Letter-Number Sequencing (LNS), Peabody Picture Vocabulary Test (PPVT), Tower of Hanoi task (TOH), and Raven's Progressive Matrices (Raven's) followed by two surveys: a Reading Background Questionnaire (RBQ) and a familiarity rating for the topics of our five reading texts (see Figure 2 for behavioral test overview).

SESSION 1: Imaging Acquisition		SESSION 2: Behavioral Tests
T1-weighted data ↓ Resting-state data ↓ Reading task data (5 runs) ↓ Diffusion Tensor Imaging (DTI) ↓ Post-scanning questionnaire	**Approximately 1-7 days**	TOH ↓ Raven's ↓ GSRT ↓ LNS ↓ PPVT ↓ ANT ↓ RBQ

Figure 1. *General Procedure*

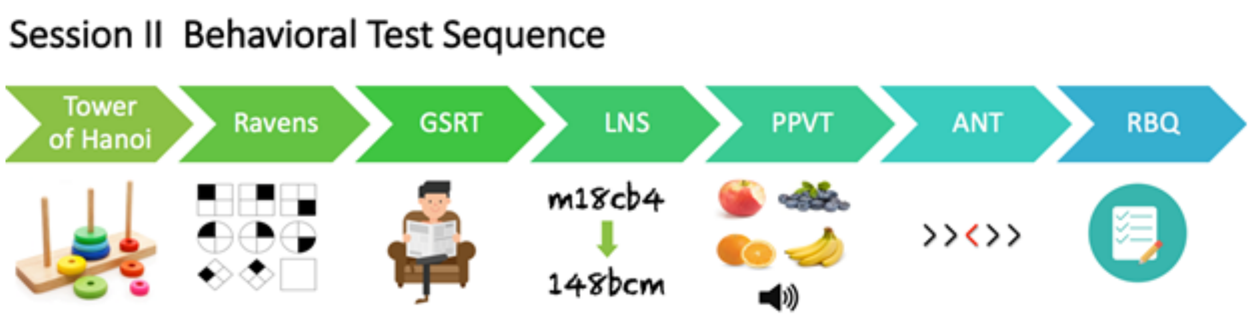

Figure 2. *Behavioral Tests Overview*

3. Organization of File Directory and Data Structure

We followed the principles of Gorgolewski et al. (2016) for Brain Imaging Data Structure (BIDS) to store the collected data as discussed above (see Figure 3 for the overall organization of file directory and data structure). We have adopted the steps proposed by Gorgolewski et al. (2016) to create a BIDS-compatible dataset including (i) converting dicom files into the NIfTI file format (ii) creating the suggested folder structure, renaming and uploading the NIfTI files including anatomical scans, functional scans and DTI-scans (iii) adding the data of the experimental paradigms we used as .tsv files and (iv) validating the dataset using the BIDS-Validator.

In the main directory of this dataset, the “dataset_description.json” file contains general information about this study.[2] “README” describes more details about the data structures. Each participant’s profile is in the “Demographics.tsv” file, which contains the participants’ demographic information.

Under the main directory, the RBQ.tsv file contains the RBQ survey results. The “T1W.json” file contains the information for the MR structural imaging acquisition parameters, and the “task-read_bold.json” and “task-rest_bold.json” files for task-based and resting state functional datasets, respectively. The “dwi.json” file contains information for the DTI acquisition parameters. In the fmap folder of each individual participant is the “sub-XX_epi.json”[3] file, which contains information of the fieldmap acquisition parameters.

Data from each participant are in separate folders numbered by the participant’s ID number, which contains four subfolders: (1) the T1-weighted data [Anat]; (2) the DTI data [DWI]; (3) the functional data folder [Func] includes five task-based sessions , one resting-state session and the physiological recordings (pulse and respiration data) , (4) the task-based fieldmap data [fmap] which contains two fieldmap files for the functional runs as well as one fieldmap for the dwi files.

[2] Updated hyperlinks to the corresponding data files of this document are posted on http://blclab.org/reading_brain.
[3] This file exists for each participant in the fmap folder. The hyperlinked file is only the data of the first subject.

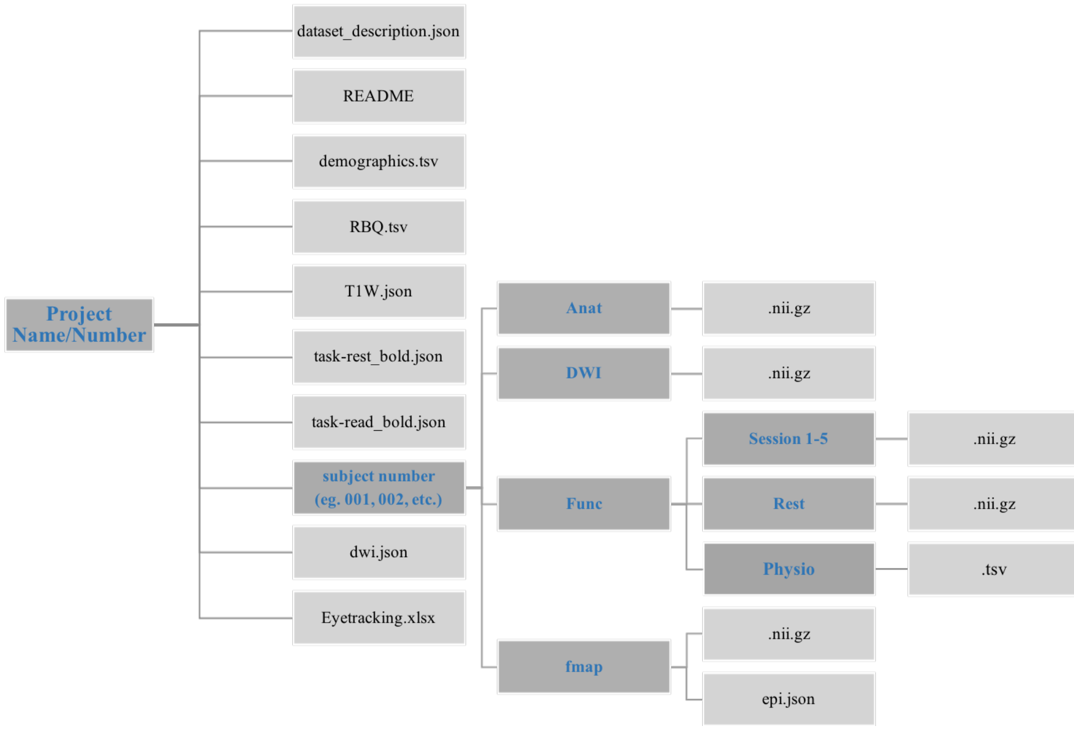

Figure 3. *Organization of File Directory and Data Structure (Folder names are in blue, and file names are in black.)*

4. Materials

Prior to the experiment, five expository texts on STEM contents for the reading task in scanner were modified from previous research stimuli (see Follmer, Fang, Clariana, Meyer, & Li, 2018, for details): Mars, Supertanker, Math, GPS, and Electric Circuits (see Appendix A for an overview of psycholinguistic variables and STEM texts).

5. MRI Data Acquisition

5.1 T1-Weighted Structural Data

All imaging data were acquired at the Center for NMR Research in the Pennsylvania State University Hershey Medical Center in Hershey, Pennsylvania. Data were acquired using a 3T Siemens Magnetom Prisma Fit scanner with a 64-channel phased array coil. All participants were first informed of the general procedure, and then underwent 6-min T1 structural scanning to acquire their anatomical data. During the T1 session, they were shown a blank screen and were informed that they could close their eyes. We acquired a MPRAGE scan with T1 weighted contrast [176 ascending sagittal slices with A/P phase encoding direction; voxel size = 1mm isotropic; FOV = 256 mm; TR = 1540 ms; TE = 2.34 ms; acquisition time = 216 s; flip angle = 9°; GRAPPA in-plane acceleration factor = 2; brain coverage is complete for cerebrum, cerebellum and brain stem]

5.2 Resting-State MRI Data

After the structural scan, participants completed a 5-min resting-state MRI session, during which participants were told to relax and stare at a cross on the center of the screen, and think about nothing in particular (see Appendix C1). The resting-state scan was an echo planar imaging (EPI) scan (voxel size = 3 mm × 3 mm × 4 mm) with a TR = 2000 ms, TE = 30 ms, flip angle = 90°; FOV = 240 mm, acquisition time = 308 s; multiband acceleration factor = 2, and a total of 34 interleaved axial slices with A/P phase encoding direction (see the file task-rest_bold.json).

5.3 fMRI Data During Reading

In addition, a reading fMRI task was administered following a practice session outside of the scanner, where participants were shown five expository texts of Science, Technology, Engineering, and Mathematics (STEM) topics sentence by sentence. Participants were instructed to click a button on a response box to proceed to the next sentence (see Appendix C2). Each sentence was presented for up to 8 seconds after which the next sentence automatically appeared on the screen. This amount of time was deemed long enough for most participants to carefully read and comprehend the sentence, but not overly long to prevent boredom.

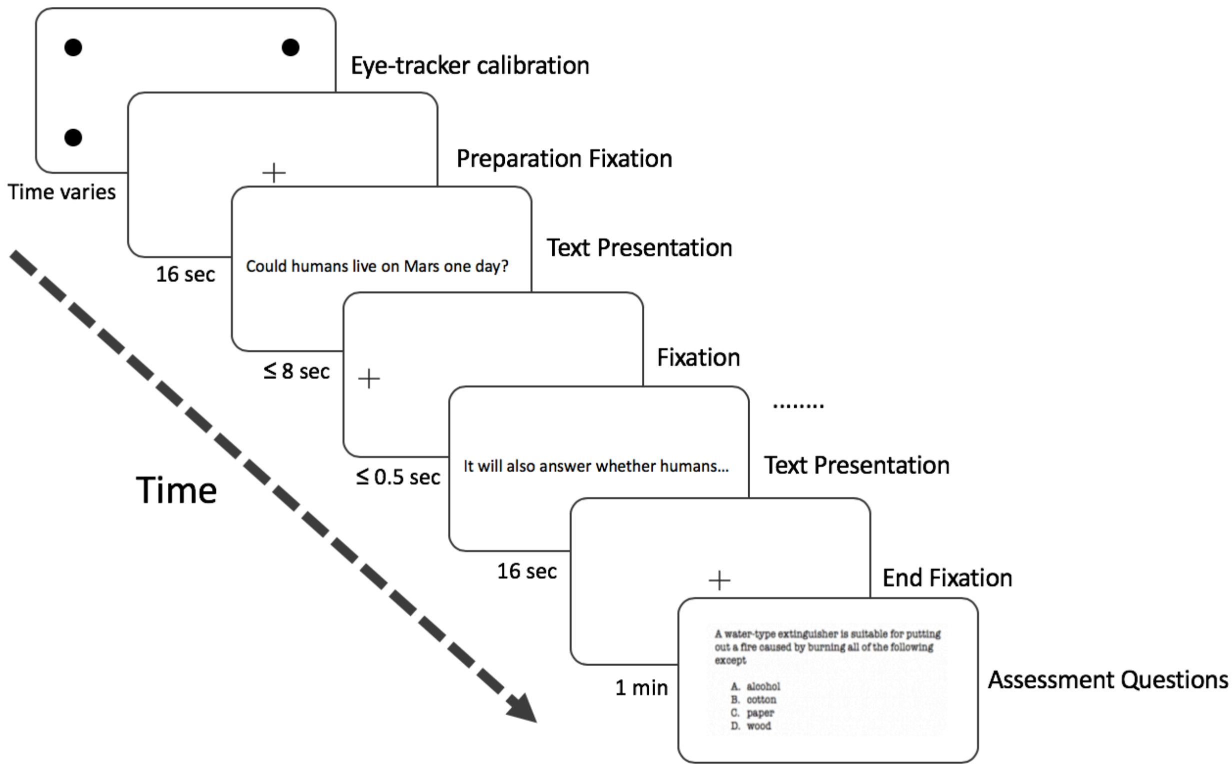

Figure 4. *Procedural Overview. After each eye-tracking calibration and the preparation fixation, participants saw each scientific text via sentence-by-sentence self-paced reading. Once text presentation is finished, participants responded to 10 multiple choice questions, one by one*.

We acquired five functional runs of T2* weighted echo planar sequence images [30 interleaved axial slices with A/P phase encoding direction; voxel size = 3 mm × 3mm × 4 mm; FOV = 240 mm; TR = 400 ms; TE = 30 ms; acquisition time varied on the speed of self-paced reading, maximal 5.1 minutes per run; multiband acceleration factor for parallel slice acquisition = 6; flip angle = 35°; where the brain coverage missed the top of the parietal lobe and the lower end of the cerebellum] (see the information in the task-read_bold.json file). Additionally, we collected a pair of spin echo sequence images with A/P and P/A phase encoding direction [30 axial interleaved slices; voxel size = 3 mm × 3mm × 4 mm; FOV = 240 mm; TR = 3000 ms; TE = 51.2 ms; flip angle = 90°] to calculate distortion correction for the multiband sequences (Glasser et al., 2013). At the end of each text, each participant answered 10 multiple-choice questions for assessing the student reader's comprehension of the texts (see Appendix E1). Figure 4 presents a flow chart of the fMRI procedure of the reading task.

5.4 Fixation-related fMRI

In fMRI studies of reading, it is important to know the exact onset time of words and phrases to convolve the hemodynamic response function (HRF) to specific task-related variance from unexplained variance.[4] In this study, we have taken advantage of a paradigm that has emerged from a number of recent studies that explore simultaneous eye-tracking and fMRI data acquisition, in a so-called 'fixation-related fMRI' method. The basic idea of this method, as first explored by Marsman et al. (2012), is to use self-paced eye movements (e.g., the onset of initial fixation at an area of interest) to convolve the hemodynamic responses and to model the psychological regressors in order to analyze fMRI data of visual processing. Following Marsman et al.'s study, Richlan et al. (2014), Henderson et al. (2015), and Schuster et al. (2016) have further demonstrated the validity of simultaneous eye-tracking and fMRI paradigms in naturalistic word and text reading. With this paradigm, participants are able to self-pace materials during reading in the scanner, in a more naturalistic manner than reading via RSVP or other experimenter-controlled stimuli presentations.

To match the fast speed of eye-movements and the cognitive processes during reading, we further used the multiband echo-planar imaging (EPI) acquisition technique (Larkman et al., 2001) to reduce the fMRI repetition time (TR) to 400 ms (see section 5.3 for details), in contrast to the typical TR of 2000 ms used in task-based fMRI studies. Multiband EPI provides greater within-participant statistical power with a higher sampling rate, a higher temporal Nyquist frequency to detect fast oscillatory neutrally generated BOLD signals (Lewis et al., 2016), and better removal of spurious non-BOLD high-frequency signal content (Todd et al., 2017). By integrating eye-

[4] Previous neuroimaging studies of texts dealt with this issue by controlling the presentation rate of the stimuli, typically with individual words or phrases shown in a rapid-serial-visual-presentation (RSVP) paradigm (Wehbe et al., 2013; Yarkoni et al., 2008). Such RSVP reading of every word at the center of the screen, however, is not as natural as reading in real-life situations.

movement and high sampling-rate fMRI data in a naturalistic paradigm, we provide a neurocognitive method for the study of naturalistic scientific text comprehension.

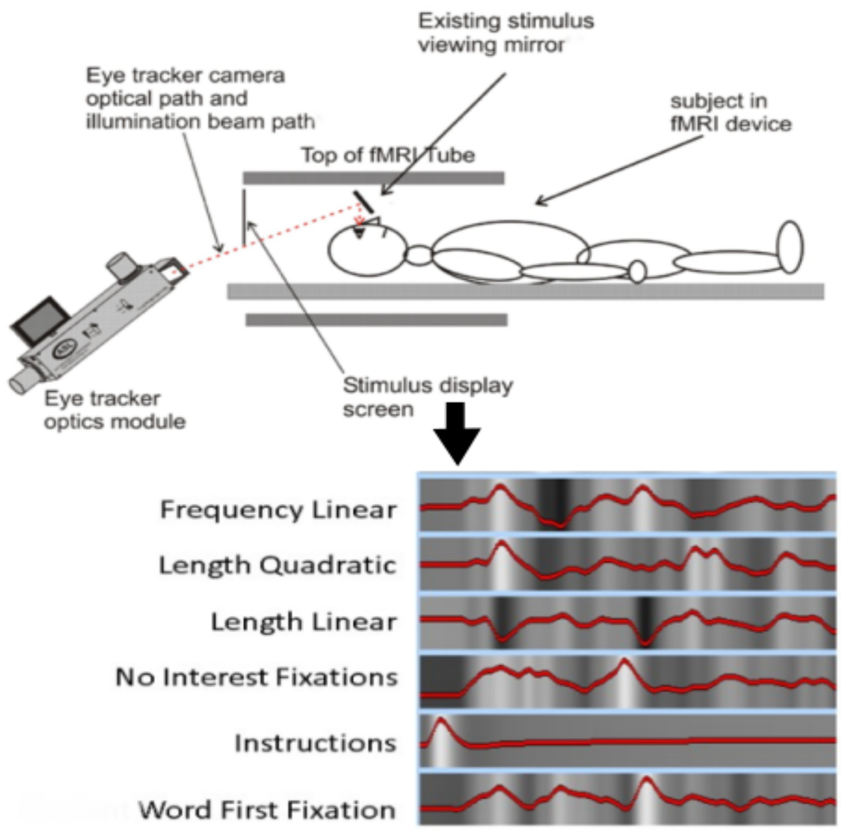

Figure 5. *Fixation-related (fire) fMRI. While participants read the texts in the scanner, their eye-tracking data are recorded. The onsets of the initial fixations of words are used as events for the generalized linear model (GLM).*

5.5 DTI Data

Diffusion tensor imaging (DTI) data were acquired from each participant [72 interleaved axial slices with A/P phase encoding direction; slice thickness = 2.0 mm (no gap); voxel size = 1.9 mm × 1.9mm × 2.0 mm; FOV = 240 mm; TR = 4160 ms; TE = 80.60 ms; flip angle = 90°; *b*-value ≥ 0 s/mm]. See detailed information in the file dwi.json. Additionally, a fieldmap sequence with voxel parameters common to the DTI was also acquired and used to correct the DTI data for geometric distortions [72 interleaved axial slices with P/A phase encoding direction; slice thickness = 2.0 mm (no gap); voxel size = 1.9 mm x 1.9mm x 2.0 mm; FOV = 240 mm; TR = 4160 ms; TE = 80.60 ms; flip angle = 90°; b-value ≥ 0 s/mm] (see the information in Section 3 and Footnote 2 regarding fieldmaps).

6. Eye-Tracking Data Acquisition and Processing

As shown in Figure 4, during fMRI data acquisition of reading task, eye movements of the participants were recorded with an Eye-Link 1000 Plus long-range mount MRI-compatible eye tracker (SR Research, 2016). The eye tracker has a sampling rate of 1000 Hz, and was mounted at the rear end of the scanner bore. Its camera captured eye movements via a reflective mirror above the MRI's head coil. The following related parameters are measured as well: distance between reader' eyes and the presenting screen = 143 cm; distance between the camera and the participant's eyes via the reflective mirror was 120 cm; presenting screen size = 35.7 cm × 57.2 cm; average word length on the screen = 3.08 cm; average distance between words = 0.95 cm. On average, a reader's visual angle when fixating on a word is 1°14¢. Recording was monocular (from the right eye), and the participant's head was stabilized in the head coil. A 13-point calibration routine preceded the experiment, followed by a validation procedure in the first run; for the remaining runs, the validation was performed and when the error exceeded 1°, the calibration would be redone. Participants saw a fixation cross for 500 ms shown on the left side of the screen before they saw each sentence of the text. They were instructed to focus on the cross while anticipating the presentation of sentences. The first fixation cross lasted for 6000 ms, providing participants with enough time to get ready and the BOLD signal to return to baseline. All other fixation crosses in between sentences were presented for 500 ms. For naturalistic reading, each text was read in a self-paced manner. Participants could press the response button to proceed to the next sentence once they finished reading a sentence. If there was no response within 8000 ms, the screen would automatically advance to the next sentence. The order of the five texts presented to participants was randomized across participants to counterbalance possible order effect.

Due to fixation drifting caused by the declining accuracy of calibration over time, eye movement data were readjusted as follows: for fixations falling outside (above or below) the range of predefined target regions where sentences are presented, manual adjustment was performed using the Data Viewer™ software from SR Research (SR Research, 2016). Instead of using auto-adjustment which brings all fixations onto one horizontal line, we performed trial-by-trial correction only along the y axis (vertical adjustment) so as to protect readers' original eye fixation patterns. Within our participant group, approximately 15% of the data needed to be manually corrected in this fashion. A detailed description of the eye-tracking data file can be found in Appendix D.

7. Behavioral Data Collection and Processing

All cognitive behavioral tests are listed below and all test scores are recorded in the Appendix Tables B1-B5. All tests except the Tower of Hanoi (see below) were presented to participants via E-Prime 2.0 (Schneider, Eschman, & Zuccolotto, 2002) with response time and accuracy data collected. These tests have been widely used in research and validated by previous studies (e.g. Poarch & van Hell, 2012; Yang, Gates, Molenaar, & Li, 2015; Yang & Li, 2012). Tower of Hanoi task was administered using the Multitowers software (Neth & Payne, 2002). For a general depiction of these tasks, see Figure 2. For details on scoring of the six tasks, see Appendix B.

7.1 Gray Silent Reading Test (GSRT)

The GSRT (Wiederholt & Blalock, 2000) measures reading comprehension competence. Up to 13 narrative texts are provided in GSRT and each text is presented along five assessment questions.

7.2 Peabody Picture Vocabulary Test (PPVT-4)

The PPVT-4 (Dunn & Dunn, 2007) measures the participant's English receptive vocabulary. For each item, the computer presented a word aurally and simultaneously presented four pictures on the screen. Participants were instructed to select the picture that matched the meaning of the heard word.

7.3 Attention Network Test (ANT)

The ANT test (Fan, McCandliss, Sommer, Raz, & Posner, 2002) measures the alerting and orienting skills of attention and the inhibitory control ability of executive function. It consisted of a flanker test in which a central arrow was presented with congruent or incongruent flanking arrows, and the participants were asked to indicate the direction of the central arrow as fast and as accurately as possible.

7.4 Letter Number Sequencing (LNS)

The LNS task is based on the Wechsler Adult Intelligence Scale (WAIS; Wechsler, Coalson, & Raiford, 1997; third edition), and measures working memory. Participants heard a series of alternating letters and numbers and were asked to recall by typing the numbers first in ascending order and then the letters in alphabetical order.

7.5 Tower of Hanoi (TOH)

The computerized Tower of Hanoi task (Klahr, 1978) is used to measure key executive functions such as planning, rule learning, and the ability to establish and maintain a goal (in this case, sets of disc arrangements). Participants are required to solve a sequence of 3-disk TOH puzzles first and move progressively to a 5-disk TOH in the standard tower-to-tower version (for details of the procedure, see Neth and Payne, 2002; see Appendix B5 for procedure used in our study).

7.6 Raven's Progressive Matrices (Raven's)

The Raven's matrices, as a test of nonverbal intelligence, measures analogical and abstract reasoning (Raven et al., 1998). It consists of 60 design problems, which are grouped into five sets of increasing difficulty. Each problem involves several pictures in a logical sequence with the last picture missing. Six or eight pictures are presented as a possible solution to complete the sequence. The participant is required to select the picture that best completes the pattern.

8. Participant Background and Experience Surveys

To evaluate the participants' reading habit as individual difference variables, all participants completed the Reading Background Questionnaire (RBQ), and a familiarity rating for the topics of our five science texts.

8.1 Reading Background Questionnaire (RBQ)

The RBQ (Follmer et al., 2018) includes 20 questions based on previous research (Loan, 2009; Olszak & Curie-Sklodowska, 2015), and assesses readers' general reading habits, preferences, and background. Scores were collected on a 4- or 5- point Likert-scale for each question item through Google Forms. The items asked about participants' reading habits on electronic media (e.g., computers, smartphones), their electronic non-reading behaviors (e.g., time spent texting friends, watching television), reading habits (amount of time spent on reading), reading preferences (e.g., enjoyment of types of books, enjoyment of books about different cultures), attitudes toward reading, and abilities of reading. See the file L1_Adults_RBQ.tsv for details. An exploratory factor analysis conducted on the RBQ data (see Follmer et al. for details) revealed two reading-related variables underlying the RBQ questions: E-device reading index (linear combination of electronic device reading and non-reading time) and reading preference index (linear combination of reading preference, reading attitude/ability and reading time).

8.2 Familiarity Rating of the Science Texts

A familiarity rating was asked of each participant to ascertain his or her familiarity with the topics of the five science texts: Mars, Supertanker, Math, GPS, and Electric Circuit. Participants were asked about how familiar they were with each topic via a 5-point Likert-scale: very little, a little, moderate, a lot, and very much. See Appendix Table B5 for detailed scores.

8.3 Post-Scanning Questionnaire

A post-experiment questionnaire was administered to each participant after their MRI scanning. Participants were asked to answer, on a 5-point scale (from 'Strongly disagree' to 'Strongly agree'), six questions (Part I) regarding the resting-state scans (e.g., whether they fell asleep or had their eyes closed, modified from the ARSQ of Diaz et al., 2014). They were further asked to answer eight questions (Part II) regarding the reading-task scans (e.g., whether the article was easy to read or the topic was familiar to them). See Appendix C3 for details.

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10. Appendices

Appendix A: Statistics and Psycholinguistic Variables of STEM Texts

Table A1. Psycholinguistic Variables of STEM Texts

Text Metrics	Math	GPS	Mars	Circuit	Supertanker
# Words	308	307	310	304	302
# Characters (excluding spaces)	1491	1476	1528	1498	1676
# Characters (including spaces)	1798	1783	1838	1800	1978
# Paragraphs	1	1	1	1	1
# Sentences	28	28	31	30	31
Avg. Words per Sentence	10.7	11.3	10.3	10.0	9.7
Avg. Characters per Word	4.7	4.6	4.7	4.8	5.4
Avg. Characters per Sentence (excluding spaces)	53.25	52.71	49.29	49.93	54.06
Avg. Characters per Sentence (including spaces)	64.21	63.68	59.29	60.00	63.81
Passive Sentences %	7.0%	10.0%	3.0%	10.0%	12.0%
Flesch Reading Ease	63.92%	65.35%	69.79%	61.85%	55.28%
Flesch-Kincaid Grade Level	6.94	6.78	6.05	7.13	8.00
Coh-Metrix L2 Readability	21.09	26.07	26.12	18.47	22.48
Coh-Metrix Narrativity	27.8%	18.9%	16.1%	15.4%	8.5%
Coh-Metrix Syntactic Simplicity	91.8%	78.8%	93.1%	96.8%	98.3%
Coh-Metrix Word Concreteness	15.4%	74.5%	88.9%	34.5%	90.7%
Coh-Metrix Referential Cohesion	77.9%	87.1%	82.4%	83.4%	46.0%
Coh-Metrix Deep Cohesion	50.8%	5.7%	24.5%	21.5%	75.8%
CELEX word frequency for content words, mean	2.08	2.14	2.19	2.02	1.90
CELEX Log frequency for all words, mean	2.85	2.89	2.72	2.94	2.61
Age of acquisition for content words, mean	376.61	344.25	322.08	410.22	340.03
Familiarity for content words, mean	564.62	575.67	562.33	548.81	554.20
Concreteness for content words, mean	352.18	406.40	410.86	390.21	431.22
Imageability for content words, mean	361.26	444.50	438.33	419.93	460.06
Maximal betweenness centrality (MBC)	.34	.29	.59	.16	.72

Note: The five STEM texts were roughly of equal number of words and sentences (see details in Appendix Table A1), with mean number of words per sentence being 10.4 (± .62) and mean number of characters per sentence, including spaces being 62.48 (± 1.92). The five texts had similar values of Flesch reading ease estimate (mean = 64.7%) and Flesch-Kincaid grade level (mean = 6.71; Flesch, 1948), both of which indicated that the texts were above average in readability. For Celex database measures, see Baayen et al. (1995); for Coh-Metrix measures, see Graesser et al. (2004). Furthermore, psycholinguistic variables of the lexical properties (word frequency, word length, etc.) of each text (see detailed information in Appendix Table A1) were derived from the English Lexicon Project (Balota et al., 2007), the Kuperman age-of-acquisition (AoA) database (Kuperman, Stadthagen-Gonzalez, & Brysbaert, 2012), the MRC Database (Coltheart, 1981) and the Brysbaert concreteness database

(Brysbaert, Warriner, & Kuperman, 2014) (see Appendix Table A1 for details). Bootstrapped One-way ANOVAs revealed no significant difference between the average values across all five texts for the average number of syllables (NSyll, $F = .05$, $p = .99$), lexical decision time (LDT, $F = 1.07$, $p = .38$), log frequency ($F = .25$, $p = .91$), naming response time (NRT, $F = 1.41$, $p = .23$), orthographic neighborhood density (OLD, $F = .04$, $p = .99$), phonological neighborhood density (PLD, $F = .34$, $p = .85$), concreteness ($F = .24$, $p = .91$), and number of phonemes (NPhon, $F = .02$, $p = .99$). However, one-way ANOVAs for word length and AoA were significant at $p < .05$ ($F = 3.27$, $F = 3.32$, respectively), suggesting that the average length of words and age at which these words are acquired may differ across the five texts. Text-wise, mean values of psycholinguistic variables were linearly correlated with linear term of MBC (OLD, $r = .92$ $p = .025$; PLD, $r = .92$, $p = .0285$; NSyll, $r = .92$, $p = .0268$; NPhon, $r = .88$, $p = .0487$; LDT, $r = .9$, $p = .0356$; NRT, $r = .91$, $p = .034$; frequency, $r = .89$, $p = .0453$; AoA, $r = .88$, $p = .049$; length, $r = .87$, $p = .053$, concreteness, $r = .88$, $p = .0487$). MBC or maximum betweenness centrality is a graph-theoretical network measure. It has been used as a tool to derive conceptual maps, a network representation of the interrelations among key terms/concepts in the text, and is often referred to as textual knowledge structure (KS; see Clariana, Engelmann, & Yu, 2013 and Li & Clariana, 2018 for application to text analyses and reading comprehension).

Appendix B: Cognitive and Linguistic Tests

Section 7 discusses the nature of the cognitive and linguistic tests we used. This appendix provides details regarding how each test was administered and scored in this study.

B1: Gray Silent Reading Test (GSRT)

The GSRT (Wiederholt & Blalock, 2000) measures reading comprehension competence. Up to 13 narrative texts are provided in the GSRT and each text is presented along five assessment questions. Adult participants in our study started with Text #8 (a text of middle-level difficulty) and were tested downward (e.g., Text #7) until the basal was reached (i.e., when all five questions were answered correctly), or upward (e.g., Text #9) until the ceiling was reached (i.e., 3 out of 5 answers were wrong). The raw scores are the total number of points counted as correct on the test, they are used in formulas that generate age equivalent percentiles and standard quotient scores. The standardized scores (quotients) have a mean of 100 and deviation of 15, and are based on the cumulative frequency distribution of the raw scores made by individuals across ages 7-18. The standardized scores (quotients) can then be converted into percentile ranks, which is popular for interpretation.

B2: Peabody Picture Vocabulary Test (PPVT-4)

The PPVT-4 (Dunn & Dunn, 2007) measures the participant's linguistic skill, specifically vocabulary size. For each item, the computer presented a word aurally and simultaneously presented four pictures on the screen. Participants were instructed to select the picture that matched the meaning of the heard word. After practice trials, the participants would start the itemset that corresponded to the participant's age, as standardized PPVT has item sets denoted by different ages. They were tested downward until the basal set was established (i.e. until only one or zero errors within the item set), and then upward until the ceiling set was reached (i.e. eight or more errors within the item set). Accuracy scores were normed by age according to the PPVT handbook.

B3: Attention Network Test (ANT)

The ANT test (Fan, McCandliss, Sommer, Raz, & Posner, 2002) measures the alerting and orienting skills of attention and the inhibitory control ability of executive function. It consisted of a flanker test in which a central arrow was presented with congruent or incongruent flanking arrows, and the participants were asked to indicate the direction of the central arrow as fast and as accurately as possible. The row of arrows might appear above or below the fixation cross. In some trials before the arrows appear, one or two asterisks would appear. Both asterisks alerted the participants that the arrow would appear soon, but only one prompted the location of the arrows as well. Three scores were derived according to Fan et al. (2002), reflecting the RT differences caused by alerting, orienting, and conflicting manipulations. The alerting score was derived from RT in the temporally informative double-cue condition subtracted from the RT in the temporally uninformative no-cue condition. The orienting scored was derived from the RT in the spatially informative cue condition subtracted from RT in the spatially uninformative central cue condition. The conflict score was derived from the RT in the congruent flanker condition from the RT in the incongruent flanker condition. All scores included only correct trials and averaged across all flanker conditions. A higher score reflected higher RTs and lower executive control in the subsequent function.

B4: Letter Number Sequencing (LNS)

The LNS task is based on the Wechsler Adult Intelligence Scale (WAIS; Wechsler, 1997; third edition), and measures working memory. Participants heard a series of alternating letters and numbers and were asked to recall by typing the numbers first in ascending order and then the letters in alphabetical order. The task began with a set size of two items (one letter plus one number) and increased by one item for every three trials until a set size of eight was reached. The participants' outputs were corrected for accidental typos (arrow keys) as well as capital letter and lower-case letter discrepancies. The longest sequence and the number of correct items from each participant were recorded. To properly reflect the difficulty of different items, size-weighted scores were calculated as the summation of the correct items' set weight (set size): that is, if the participant was correct in three items with a weight of two, one item with a weight of three, and two items with a weight of four, the score would be calculated as $3 \times 2 + 1 \times 3 + 2 \times 4 = 17$.

B5: Tower of Hanoi (TOH)

The computerized Tower of Hanoi task (Klahr, 1978) was used to measure key executive functions such as planning, rule learning, and the ability to establish and maintain a goal (in this case, sets of disc arrangements). The "towers" consist of disks of varying sizes arranged from largest to smallest from the bottom-up on a peg, with a total of three pegs available on the full apparatus. The objective of the task is to move the discs from the left-most peg to the right-most peg with the same size configuration (i.e., largest to smallest). Participants are only allowed to move one disk at a time with a cursor, and at no time can a larger disk be placed on top of a smaller disk. A practice trial consisting of two disks was given to the participant prior to the task. After the practice trial, participants had 5 minutes to complete as many sets as they could, starting with the three-disk set (increasing to four, then five, then six per disk set until 5 minutes is up). The program (Multitowers software; Neth & Payne, 2002) recorded the movement of each disk unto a different peg, as well as the reaction time for each move. In the analysis, the total time used for a set as well as the number of moves exceeding the minimal necessary number of moves was computed for each participant.

B6: Raven's Progressive Matrices (RAVEN's)

The Raven's Progressive Matrices was used to measure abstract reasoning. The test was administered individually and the time limit for this study was 10 minutes. Participants were instructed to select the piece that correctly completes the matrix out of six or eight options. Raw scores are tallied by the number of questions answered correctly. One point was given for each correct matrix. Participants would begin with Set A and move gradually to Set E, and due to time constraints of 10 min (when they had to stop), not all participants completed all the trials in the later sets.

Table B1. Comprehension of Science Text Scores

ID	Gender	Age	Mars	Supertanker	Math	GPS	Circuit
1	F	18	0.8	0.7	0.8	0.7	0.9
2	M	24	0.9	0.9	1	1	1
3	F	23	0.9	1	1	1	1
4	F	23	1	1	1	1	1
5	F	23	1	0.7	1	0.9	0.8
6	F	27	0.9	1	1	1	0.9
7	M	28	1	0.9	1	0.8	1
8	M	22	0.9	1	0.9	0.9	0.8
9	F	23	0.8	0.6	0.8	0.9	0.8
10	M	18	1	0.9	1	0.8	0.9
11	F	24	0.9	0.8	0.9	0.8	1
12	M	21	0.9	0.9	1	1	1
13	M	19	1	0.9	1	1	1
14	M	26	1	0.9	0.9	1	1
15	F	23	1	0.9	1	1	1
16	F	29	1	0.8	1	1	1
17	M	21	0.8	1	0.7	0.9	0.9
18	M	25	0.9	0.9	1	1	1
19	F	26	0.9	0.7	0.9	0.9	0.9
20	F	23	0.8	0.9	0.9	0.9	1
21	F	40	0.7	1	1	0.9	1
22	M	18	0.8	0.6	0.9	0.9	1
23	F	22	1	0.9	1	0.9	1
24	F	22	1	0.9	1	0.7	0.8
25	M	21	1	0	1	0.9	1
26	M	18	0.8	1	1	0.8	1
27	F	27	0.9	0.9	1	0.9	1
28	F	18	0.9	0.8	1	0.7	0.9
29	F	24	0.8	0.8	0.8	1	1
30	M	18	0.9	1	1	1	0.9
31	M	35	1	1	1	1	1
32	F	22	1	0.9	1	0.9	0.9
33	F	18	0.7	0.7	0.8	1	0.9
34	F	18	0.9	0.8	0.9	0.9	1
35	M	21	0.9	1	1	0.9	1
36	M	18	1	0.9	1	0.8	1
37	F	18	1	0.8	0.9	0.9	1
38	M	18	0.9	0.8	0.9	0.9	1
39	M	18	1	0.8	0.8	0.9	1
40	F	19	1	0.8	0.9	0.8	1
41	M	19	1	0.9	1	0.8	0.9
42	M	24	1	0.9	1	1	1
43	M	24	1	1	0.9	1	0.9
44	M	32	0.9	0.9	0.9	0.5	1
45	M	31	1	0.8	0.8	0.8	0.8
46	F	21	0.9	1	1	1	1
47	F	27	1	1	1	1	1
48	M	26	0.9	1	1	1	1
49	F	21	0.7	1	1	0.8	0.8
50	F	21	0.8	0.9	1	1	0.9
51	M	21	1	0.9	1	1	1
52	F	22	0.9	1	0.9	0.8	0.9

Note: The numbers (excluding the ID and Age columns) indicate the comprehension scores (accuracy rate from 0 to 1) for the 5 science texts.

Table B2. Tests Assessing Cognitive Control and Working Memory

ID	ANT Alerting	ANT Orienting	ANT Conflict	LNS Longest	LNS Accuracy	LNS Weighted
1	37	10	142	7	14	59
2	14	72	112	n/a	n/a	n/a
3	42	50	94	7	11	45
4	87	49	63	6	13	48
5	39	38	75	7	14	57
6	19	44	138	8	15	67
7	24	80	73	8	13	70
8	10	10	84	6	13	52
9	19	44	300	7	14	58
10	25	57	126	7	11	42
11	73	28	130	5	10	35
12	64	55	108	7	12	58
13	38	18	84	n/a	n/a	n/a
14	50	46	144	6	12	52
15	12	31	104	8	16	71
16	33	35	108	6	14	54
17	28	27	107	4	6	21
18	n/a	n/a	n/a	n/a	n/a	n/a
19	55	44	150	5	11	40
20	56	54	73	6	12	46
21	21	34	89	7	14	63
22	82	44	80	6	13	52
23	47	71	78	6	13	48
24	88	64	36	7	9	31
25	83	33	85	8	12	47
26	140	34	267	7	14	56
27	7	48	89	8	14	57
28	35	30	66	8	18	82
29	74	35	142	5	12	42
30	36	22	64	8	17	76
31	15	27	132	5	10	35
32	37	77	76	8	15	67
33	22	27	74	n/a	n/a	n/a
34	54	72	92	8	16	81
35	28	22	97	8	18	82
36	41	43	122	5	10	35
37	36	39	126	6	11	40
38	46	39	123	5	8	28
39	25	14	130	5	9	29
40	n/a	n/a	n/a	n/a	n/a	n/a
41	39	30	106	8	15	63
42	54	32	70	6	13	48
43	46	3	95	7	14	60
44	69	95	116	6	10	43
45	38	8	126	6	12	43
46	59	14	94	7	15	61
47	23	61	114	7	14	64
48	55	50	106	8	17	49
49	23	31	115	7	11	41
50	90	22	90	6	13	49
51	61	7	110	7	8	32
52	46	18	120	8	13	52

*Note***:** Table B2 includes cognitive tests scores assessing executive functioning. LNS Longest is the longest sequence reported by the participant. LNS Accuracy is the number of correct items reported by the participant. LNS weighted reflects the digit length-weighted score. Subjects 18 and 40 did not return to Session 2 to complete the tests (marked as 'n/a' in the table) and Subjects 13 and 33 had an issue with the equipment while competing the LNS task (marked as 'n/a' in the table).

Table B3. Tests Assessing Planning and Reasoning Abilities

ID	Raven's N Trials	Raven's Raw Scores	TOH RT	TOH Moves
1	59	45	67.79	8
2	55	50	23.52	2
3	56	50	57.32	18
4	48	47	62.49	6
5	60	45	106.79	17
6	59	52	19.88	0
7	51	46	21.38	1
8	54	43	11.68	1
9	57	39	310.94	20
10	51	47	21.38	3
11	51	46	21.38	6
12	60	38	45.65	0
13	60	54	17.60	0
14	47	45	18.09	1
15	48	45	31.74	0
16	55	50	36.20	0
17	54	50	36.52	6
18	n/a	n/a	n/a	n/a
19	46	40	77.62	6
20	60	46	16.64	0
21	49	46	23.21	0
22	50	48	38.56	5
23	48	43	21.09	1
24	52	41	34.88	2
25	57	47	33.69	4
26	47	40	291.76	46
27	52	44	57.44	10
28	57	54	12.49	1
29	39	37	37.94	6
30	48	44	20.76	0
31	42	38	57.37	6
32	49	47	26.93	2
33	56	44	29.90	2
34	35	31	25.70	3
35	46	44	24.25	0
36	51	44	42.14	4
37	56	44	35.16	2
38	43	38	119.37	15
39	57	47	22.44	4
40	n/a	n/a	n/a	n/a
41	60	43	16.25	0
42	48	46	n/a	n/a
43	59	49	15.43	0
44	52	39	35.62	2
45	55	45	57.24	1
46	55	51	32.25	2
47	47	47	31.68	8
48	41	41	63.56	5
49	60	37	18.93	2
50	58	51	32.11	4
51	55	45	13.81	0
52	33	31	43.36	3

Note: Table B3 includes cognitive test scores that assess abstract reasoning. Due to time constraints, not all participants completed the total 60 questions. Ravens N Trials is the number of trails completed. Ravens Raw Scores is the number of trials correctly completed. TOH RT is the reaction time in seconds for the participant to complete the 3-level disk task. TOH moves refers to moves participants made in addition to the 7 necessary steps to complete a Tower of Hanoi task on level 3 which was used as a baseline (e.g., '0' on the last column indicates that the participant completed the 3-level disk task with 7 moves, and '1' indicates the participant completed it with 8 moves). Subjects 18 and 40 did not return to Session 2 to complete the tests (marked as 'n/a' in the table). Subject 42 did not perform the TOH task.

Table B4. Tests Assessing Reading and Vocabulary Abilities

ID	GSRT Raw	GSRT Quotient	GSRT Rank	PPVT Raw	PPVT Normed
1	53	105	63	n/a	n/a
2	62	121	92	218	24
3	61	119	90	n/a	n/a
4	64	125	95	220	23
5	53	105	63	204	23
6	58	113	81	213	27
7	59	115	84	217	28
8	50	99	47	203	22
9	56	109	73	184	23
10	59	115	84	n/a	n/a
11	60	117	87	210	24
12	61	119	90	201	21
13	59	115	84	195	19
14	61	119	90	210	26
15	63	123	94	216	23
16	63	123	94	220	29
17	56	109	73	195	21
18	n/a	n/a	n/a	n/a	n/a
19	48	97	42	188	26
20	59	115	84	207	23
21	60	117	87	214	40
22	44	91	27	n/a	n/a
23	62	121	92	214	22
24	45	93	32	184	22
25	51	101	53	210	21
26	43	89	23	n/a	n/a
27	56	109	73	200	27
28	56	109	73	n/a	n/a
29	47	95	37	204	24
30	56	109	73	n/a	n/a
31	57	111	77	212	35
32	60	117	87	213	22
33	46	94	35	n/a	n/a
34	57	111	77	202	18
35	63	123	94	219	21
36	54	107	68	n/a	n/a
37	50	99	47	205	18
38	56	109	73	205	18
39	58	113	81	200	18
40	n/a	n/a	n/a	n/a	n/a
41	54	107	68	n/a	n/a
42	61	119	90	210	24
43	62	121	92	218	24
44	30	66	1	210	32
45	50	99	47	212	31
46	65	125	95	215	21
47	65	125	95	221	27
48	62	121	92	213	26
49	49	98	45	197	21
50	56	109	73	202	21
51	47	95	37	206	21
52	62	121	92	186	22

Note: Table B4 includes cognitive test scores that assess reading comprehension (GSRT) and vocabulary size (PPVT). GSRT normed and PPVT normed are the age-normed standard scores (quotients) for each participant. GSRT Rank refers to the percentile ranks corresponding to the raw score. Subjects 18 and 40 did not return to Session 2 to complete the tests (marked as ‘n/a’ in the table). Several other subjects did not perform the PPVT task.

Table B5. Familiarity Ratings of Science Topics

ID	Astronomy	Engineer	Environment	Math	Physics	Technology
1	2	1	3	4	1	4
2	2	3	4	3	3	4
3	3	1	5	2	1	1
4	2	2	4	3	2	3
5	3	1	5	5	1	5
6	1	1	2	3	2	3
7	1	2	3	4	2	2
8	2	3	3	3	3	3
9	1	1	2	2	2	3
10	2	5	3	4	5	5
11	1	1	3	3	3	3
12	2	2	3	3	4	4
13	2	1	3	3	2	5
14	2	1	3	4	3	2
15	2	1	2	1	3	1
16	1	2	2	3	2	2
17	1	1	1	1	1	5
18	n/a	n/a	n/a	n/a	n/a	n/a
19	3	2	4	1	2	3
20	4	1	3	3	3	3
21	1	1	3	4	1	3
22	1	3	3	4	3	4
23	1	2	3	3	3	2
24	1	1	5	1	1	1
25	2	2	3	3	2	3
26	3	3	4	4	4	4
27	2	1	2	3	2	2
28	3	3	2	4	4	2
29	4	3	4	4	4	4
30	4	1	2	2	1	4
31	3	2	3	3	3	4
32	3	3	4	4	3	4
33	1	1	2	1	3	1
34	2	2	2	3	2	3
35	2	4	2	3	3	3
36	2	1	1	3	3	5
37	3	4	3	4	4	5
38	1	1	3	2	1	2
39	1	1	3	2	1	3
40	n/a	n/a	n/a	n/a	n/a	n/a
41	2	1	2	3	3	3
42	2	5	3	5	5	5
43	2	2	2	3	3	3
44	2	2	3	4	2	5
45	2	3	3	4	3	5
46	1	3	4	3	3	3
47	2	5	5	4	4	3
48	2	5	4	4	4	3
49	1	3	1	2	2	3
50	2	5	2	5	3	3
51	2	3	3	3	3	3
52	1	1	1	3	3	3

Note: Table B5 includes familiarity scores of different participants. Subjects 18 and 40 did not return to Session 2 to complete the ratings (marked as ‘n/a’ in the table).

Appendix C: Instructions for MRI Scanning and Post-Scanning Questionnaire

C1: Resting-State

For the next six minutes, please look at the cross on the screen, and don't think about anything in particular. Please relax, but do not fall asleep.

C2: Reading Task

You will see a fixation cross on the screen. Sentences will appear following the cross. Please make sure to press any button once you're done reading the sentence to proceed.

C3: Post-Scanning Questionnaire

Thank you for having done such a great job in the scanner! We would like to ask you to answer a few quick questions below. This should not take more than 2 minutes.
If you have any other comments or suggestions, please add them here [ ].

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Part I: Resting-State					
I was sleepy.	O	O	O	O	O
I fell asleep or blanked/zoned out at some point.	O	O	O	O	O
I had my eyes closed	O	O	O	O	O
I didn't know what I was supposed to do at some point.	O	O	O	O	O
I felt anxious/nervous inside the scanner.	O	O	O	O	O
The scanner noise kept me awake.	O	O	O	O	O
Part II: Reading Task					
I was sleepy	O	O	O	O	O
I fell asleep or blanked/zoned out at some point.	O	O	O	O	O
The articles were easy	O	O	O	O	O
The articles were too long.	O	O	O	O	O
I thought the articles were very interesting.	O	O	O	O	O
The articles dealt with topics I know a lot about.	O	O	O	O	O
The questions were easy to answer.	O	O	O	O	O
The questions were related to the content of the preceding text.	O	O	O	O	O

Appendix D: Descriptions of the Eye-Tracking Data File

Table D1. Column Descriptions

Column Name	Descriptions
RECORDING_SESSION_LABEL	Subject Number & Session Number. For instance, "S01_2" stands for the first subject's second session
Sentence	Text ID & Sentence ID. For instance, "t.05.13" stands for the 13th sentence in text #5
IA_ID	Word ID in the current sentence. For instance, 5 stands for the 5th word in the current sentence
TRIAL_DWELL_TIME	Total fixation duration time in the current sentence (in milliseconds)
TRIAL_FIXATION_COUNT	Total number of fixations in the current sentence
TRIAL_IA_COUNT	Total number of words that contained in the current sentence
TRIAL_INDEX	A count of sentence order in the current text (in even numbers)
IA_RUN_COUNT	Number of times the current word was entered and left (runs)
IA_DWELL_TIME	Dwell time (i.e., summation of the duration across all fixations) on the current word
IA_FIRST_FIXATION_DURATION	Duration of the first fixation event that was within the current word.
IA_FIRST_FIXATION_TIME	Start time of the first fixation to enter the current word.
IA_SECOND_FIXATION_DURATION	Duration of the second fixation in IA, regardless of run
IA_SECOND_FIXATION_TIME	Time of the second fixation in IA, regardless of run
IA_THIRD_FIXATION_DURATION	Duration of the third fixation in IA, regardless of run
IA_THIRD_FIXATION_TIME	Time of the third fixation in IA, regardless of run
IA_REGRESSION_IN_COUNT	Number of times the current word was entered from a higher IA_ID (from the right in English).
IA_REGRESSION_OUT_COUNT	Number of times the current word was exited to a lower IA_ID (to the left in English) before a higher IA_ID was fixated in the trial
IA_REGRESSION_PATH_DURATION	The summed fixation duration from when the current word is first fixated until the eyes enter a word with a higher IA_ID
Skip Count	Total number of skips in the current sentence
Count Regress_Out	Total number of regressions happened in the current sentence

Note: Corresponding Text IDs used in the current study are: 01-Mars; 02-Supertanker; 03-Math; 04-GPS; 05-Electric Circuit.

Table D2. Areas of Interest (AOI) Setup

	Mars	Supertanker	Math	GPS	Electric Circuit
1	Could	How	Two	Global	Engineers
2	humans	can	important	Positioning	design
3	live	engineers	math	System	electrical
4	on	help	concepts	(GPS)	circuits
5	Mars	prevent	are	is	to
6	some	spills	combinations	a	power
7	day?	of	and	system	homes
8	Scientists	oil	permutations.	that	and
9	ask	from	Combinations	helps	buildings.
10	this	supertankers?	and	us	Electrical
11	question	Supertankers	permutations	navigate.	circuits
12	because	are	are	GPS	are
13	Earth	huge	similar	is	closed
14	and	ships	in	a	paths
15	Mars	that	several	system	that
16	are	carry	ways.	of	electricity
17	similar.	oil	Both	24	flows
18	Similar	over	refer	or	through.
19	to	the	to	more	This
20	Earth	oceans.	sets	satellites	means
21	day,	A	of	in	that
22	Mars	supertanker	objects	space.	the
23	day	can	that	These	entire
24	is	contain	you	satellites	path
25	about	about	pick	orbit	must
26	24	a	and	at	be
27	hours	half-million	arrange	about	connected
28	long.	tons	in	12	like
29	Also,	of	order.	miles	a
30	both	oil.	A	above	loop.
31	planets	A	set	the	Imagine
32	are	supertanker	could	Earth.	a
33	near	is	be	Different	simple
34	the	the	the	satellites	circuit
35	Sun	size	numbers	orbit	made
36	in	of	1	the	with
37	our	about	through	Earth	a
38	solar	five	9	in	battery
39	system.	football	or	different	and
40	Earth	fields.	available	locations.	a
41	is	A	pizza	They	piece
42	the	supertanker	toppings.	circle	of
43	3rd	cargo	For	the	wire.
44	planet	area	combinations	Earth	Now
45	and	could	and	along	connect
46	Mars	hold	permutations,	1	each
47	the	the	items	of	end
48	4th	Empire	are	6	of
49	planet	State	selected	orbits	the

50	from	Building.	from	continuously.	wire
51	the	Most	a	They	to
52	Sun.	of	set.	send	different
53	Mars	the	For	information	ends
54	also	world	example,	to	of
55	has	oil	we	a	the
56	an	is	can	GPS	battery.
57	axial	transported	select	receiver	Your
58	tilt	by	01. Mär	on	piece
59	similar	these	from	Earth.	of
60	to	supertankers.	the	The	wire
61	Earth	Disasters	set	information	and
62	axial	occur	01. Sep	is	battery
63	tilt.	when	to	transmitted	now
64	An	wrecked	count	across	make
65	axial	supertankers	and	space	a
66	tilt	spill	order.	via	circle
67	gives	oil	However,	radio	or
68	both	into	combinations	signals.	circular
69	planets	the	and	Radio	path.
70	seasons	ocean.	permutations	signals	One
71	with	As	are	travel	end
72	temperature	a	calculated	through	of
73	changes.	result	differently.	space	the
74	Just	of	When	like	battery
75	like	these	we	sound	is
76	Earth,	oil	compute	waves	positive
77	Mars	spills,	a	through	and
78	has	the	combination,	a	the
79	cold	environment	the	canyon.	other
80	winters	is	item	Imagine	end
81	and	damaged.	order	you	negative.
82	warmer	In	does	and	Electrons
83	summers.	1967	not	your	will
84	Like	a	matter.	friend	flow
85	Earth,	supertanker	A	are	across
86	Mars	crashed	combination	at	this
87	has	near	of	different	circuit
88	winds,	the	1	sides	through
89	weather,	shores	2	of	the
90	dust	of	3	a	wire.
91	storms,	England.	is	canyon.	You
92	and	This	the	You	have
93	volcanoes.	crash	same	shout	just
94	But	resulted	as	to	created
95	in	in	the	your	a
96	some	washing	combination	friend	simple
97	ways,	ashore	of	and	electrical
98	Earth	200	3	she	circuit.
99	and	dead	2	hears	Removing
100	Mars	seabirds.	1	you	the
101	are	In	Another	after	wire
102	different.	1989	example	a	from
103	Differences	another	of	short	the

104	include	supertanker	a	delay.	battery
105	temperature,	spilled	combination	This	will
106	length	oil	is	delay	stop
107	of	into	picking	is	the
108	a	Alaska	pizza	the	flow
109	year,	coast.	toppings.	time	of
110	and	The	Suppose	that	electrons.
111	gravity.	spilled	you	sound	Now
112	The	11	pick	waves	imagine
113	average	million	three	need	that
114	temperature	gallons	toppings:	to	you
115	is	of	cheese,	reach	want
116	-81	oil	pepperoni,	the	to
117	deg	caused	and	other	connect
118	F	1	sausage.	side.	the
119	on	otters	You	Similarly,	battery
120	Mars,	to	can	the	to
121	but	die.	also	satellite	a
122	57	Oil	say	in	lightbulb.
123	deg	spills	that	space	First
124	F	from	you	sends	the
125	on	supertankers	pick	a	wire
126	Earth.	also	sausage,	radio	is
127	A	kill	pepperoni,	signal	cut
128	Martian	drifting	and	at	in
129	year	microscopic	cheese.	one	the
130	is	plants.	Here	time.	middle
131	almost	These	you	After	and
132	twice	plants	have	a	breaks
133	as	provide	a	delay	the
134	long	food	combination	the	circuit.
135	as	for	of	radio	Then
136	an	sea	three	signal	a
137	Earth	life,	things	arrives	lightbulb
138	year.	such	in	at	is
139	Earth	as	two	the	inserted
140	gravity	whales	different	GPS	to
141	is	and	orders.	receiver	reconnect
142	almost	shrimp.	But	on	the
143	3	The	the	Earth.	circuit.
144	times	plants	pizzas	The	The
145	stronger	also	you	receiver	electrical
146	than	produce	get	records	circuit
147	Martian	70	are	the	is
148	gravity.	percent	the	precise	complete
149	Given	of	same	time	again
150	the	the	because	when	and
151	similarities,	world	the	the	electrons
152	can	oxygen	order	radio	are
153	humans	supply.	does	signal	flowing.
154	go	Oil	matter.	arrives.	Electricity
155	to	spills	However,	It	now
156	Mars	result	order	then	flows
157	and	partly	does	calculates	through

158	live	from	matter	the	the
159	there?	limitations	when	difference	lightbulb,
160	NASA	in	we	between	lighting
161	scientists	engineering.	compute	these	it
162	want	Supertankers	a	two	up.
163	to	lack	permutation.	times.	If
164	answer	double	1,2	This	the
165	this	bottom	0,3	time	circuit
166	question.	hulls	and	difference	is
167	NASA	for	3,2	is	now
168	oversees	extra	,	the	broken,
169	U.S.	protection.	1	travel	the
170	research	Supertankers	are	time	lightbulb
171	on	lack	different	of	will
172	space	extra	permutations	the	go
173	exploration.	power	of	radio	out.
174	NASA	and	these	signal.	You
175	scientists	steering	three	The	can
176	send	equipment	numbers.	GPS	also
177	devices	for	In	uses	add
178	called	safety.	permutations	this	a
179	spacecraft	Supertankers	different	travel	switch
180	to	also	orders	time	in
181	explore	have	of	to	the
182	Mars.	only	items	figure	circuit
183	The	one	have	out	to
184	spacecraft	boiler	different	how	break
185	carry	to	meanings.	far	it
186	rovers	provide	Imagine	the	or
187	that	the	you	satellite	connect
188	can	ship	can	is.	it.
189	rove	power.	pick	It	This
190	or	Supertankers	only	uses	allows
191	move	have	one	the	you
192	around.	only	for	formula	to
193	These	one	lunch:	“distance	turn
194	wheeled	propeller	pizza,	=	on
195	rovers	to	pasta,	time	or
196	can	steer	or	(T)	turn
197	explore	the	rice.	x	off
198	characteristics	huge	You	rate	the
199	of	ship.	say	of	lightbulb.
200	the	Lack	pizza	transmission	A
201	planet.	of	is	(C)”	simple
202	They	such	your	.	electrical
203	can	backup	favorite	T	circuit
204	take	components	and	is	contains
205	pictures	causes	rice	the	several
206	of	problems	is	travel	parts.
207	mountains,	during	your	time	These
208	plains,	emergencies.	least	of	include
209	and	Emergencies	favorite.	the	a
210	dust	for	So	radio	source,
211	storms	supertankers	your	signal.	a

212	on	are	order	C	path,
213	Mars.	ocean	of	is	and
214	One	storms	preference	the	a
215	of	and	is:	speed	resistor.
216	these	coastal	1)	of	The
217	NASA	reefs.	pizza,	light,	source
218	rovers	Solutions	2)	more	provides
219	is	to	pasta,	than	the
220	named	problems	and	186	energy
221	Curiosity.	with	3)	miles	to
222	Curiosity	supertankers	rice.	per	an
223	found	include	If	second.	electrical
224	evidence	three	pizza	T	circuit.
225	that	tactics.	runs	x	In
226	soil	Supertankers	out,	C	our
227	on	must	the	calculates	example
228	Mars	be	waiter	the	above,
229	contains	built	will	distance	the
230	2%	with	give	between	source
231	water.	added	you	the	is
232	NASA	hulls,	pasta	receiver	the
233	has	boilers,	and	and	battery.
234	planned	and	not	each	Batteries
235	a	propellers.	rice.	satellite.	can
236	new	These	But	Different	differ
237	mission	provide	your	satellites	in
238	called	extra	friend	have	voltage,
239	Mars	safety,	may	different	the
240	2020	control,	have	distances	electrical
241	This	and	a	from	potential
242	mission	backup	different	the	or
243	will	in	order	receiver.	force
244	use	emergencies.	of	This	The
245	a	Also,	preference.	information	path
246	new	officers	Your	helps	is
247	car-sized	need	friend	the	the
248	rover	top	order	receiver	closed
249	to	training	could	determine	loop
250	examine	to	be:	its	with
251	Mars.	run	1)	location	wires
252	The	and	rice,	on	that
253	new	maneuver	2)	Earth.	connect
254	rover	their	pasta,	The	to
255	will	ships.	and	precise	the
256	contain	Supertanker	3)	location	source.
257	additional	simulators	pizza.	is	Electrons
258	instruments	at	So	calculated	flow
259	to	some	two	based	through
260	study	facilities	orders	on	the
261	Mars.	provide	of	geometry	path
262	For	top	the	of	as
263	example,	training.	same	distances.	electric
264	one	Finally,	items	A	currents.
265	instrument	ground	mean	GPS	Electric

266	will	control	something	device	currents
267	take	stations	quite	that	increase
268	images	should	different.	you	with
269	beneath	be	Permutation	carry	increased
270	Mars	installed	allows	in	voltage.
271	surface.	near	us	your	The
272	Another	the	to	car	resistor
273	instrument	shore.	count	is	is
274	will	Ground	all	a	any
275	attempt	control	the	small	device
276	to	stations	possible	receiver.	that
277	make	would	orders	Radio	reduces
278	oxygen	act	of	signals	the
279	from	like	items.	from	electric
280	carbon	airplane	Given	the	current.
281	dioxide.	control	three	satellites	It
282	Mars	towers.	numbers	are	creates
283	2020	They	1,2,3,	updated	resistance
284	will	would	we	as	or
285	help	guide	can	the	impedance
286	scientists	supertankers	derive	device	in
287	answer	safely	6	moves.	the
288	important	on	permutations.	At	electrical
289	questions.	the	These	least	circuit.
290	It	oceans	include	4	In
291	will	along	1,2,3	satellites	our
292	explore	coasts.	/	are	example
293	whether	This	1,3,2	involved	above,
294	there	ensures	/	to	the
295	has	safety	2,1,3	pinpoint	resistor
296	been	in	/	the	is
297	life	shipping	2,3,1	device	the
298	on	lanes	/	location.	lightbulb.
299	Mars.	and	3,1,2	GPS	Electric
300	It	along	/	devices	currents
301	will	dangerous	3,2,1.	provide	decrease
302	also	coasts.	These	maps	with
303	answer		sequences	and	increased
304	whether		in	directions	resistance.
305	humans		different	that	
306	can		orders	help	
307	live		are	people	
308	on		different	travel.	
309	Mars		permutations.		
310	in				
311	the				
312	future.				

Note: The areas of interest (AOI) of the eye-tracking data are set on word level.

Appendix E: Reading Materials and Assessments

E1: Five Texts Participants Read

Mars

Could humans live on Mars some day? Scientists ask this question because Earth and Mars are similar. Similar to Earth's day, Mars's day is about 24 hours long. Also, both planets are near the Sun in our solar system. Earth is the 3rd planet and Mars the 4th planet from the Sun. Mars also has an axial tilt similar to Earth's axial tilt. An axial tilt gives both planets seasons with temperature changes. Just like Earth, Mars has cold winters and warmer summers. Like Earth, Mars has winds, weather, dust storms, and volcanoes. But in some ways, Earth and Mars are different. Differences include temperature, length of a year, and gravity. The average temperature is -81º F on Mars, but 57º F on Earth. A Martian year is almost twice as long as an Earth year. Earth's gravity is almost 3 times stronger than Martian gravity. Given the similarities, can humans go to Mars and live there? NASA scientists want to answer this question. NASA oversees U.S. research on space exploration. NASA scientists send devices called spacecraft to explore Mars. The spacecraft carry rovers that can rove or move around. These wheeled rovers can explore characteristics of the planet. They can also show land characteristics and weather on Mars. One of these NASA rovers is named Curiosity. Curiosity found evidence that soil on Mars contains 2% water. NASA has planned a new mission called Mars 2020. This mission will use a new car-sized rover to examine Mars. The new rover will contain additional instruments to study Mars. For example, one instrument will take images beneath Mars's surface. Another instrument will attempt to make oxygen from carbon dioxide. Mars 2020 will help scientists answer important questions. It will explore whether there has been life on Mars. It will also answer whether humans can live on Mars in the future.

Supertanker

How can engineers help prevent spills of oil from supertankers? Supertankers are huge ships that carry oil over the oceans. A supertanker can contain about a half-million tons of oil. A supertanker is the size of about five football fields. A supertanker's cargo area could hold the Empire State Building. Most of the world's oil is transported by these supertankers. Disasters occur when wrecked supertankers spill oil into the ocean. As a result of these oil spills, the environment is damaged. In 1967, a supertanker crashed near the shores of England. This crash resulted in washing ashore 200,000 dead seabirds. In 1989, another supertanker spilled oil into Alaska's coast. The spilled 11 million gallons of oil caused 1,000 otters to die. Oil spills from supertankers also kill drifting microscopic plants. These plants provide food for sea life, such as whales and shrimp. The plants also produce 70 percent of the world's oxygen supply. Oil spills result partly from limitations in engineering. Supertankers lack double bottom hulls for extra protection. Supertankers lack extra power and steering equipment for safety. Supertankers also have only one boiler to provide the ship power. Supertankers have only one propeller to steer the huge ship. Lack of such backup components causes problems during emergencies. Emergencies for supertankers are ocean storms and coastal reefs. Solutions to problems with supertankers include three tactics. Supertankers must be built with added hulls, boilers, and propellers. These provide extra safety, control, and backup in emergencies. Also, officers need top training to run and maneuver their ships. Supertanker simulators at some facilities provide top training. Finally, ground control stations should be installed near the shore. Ground control stations would act like airplane control towers. They would guide supertankers safely on the oceans along coasts. This ensures safety in shipping lanes and along dangerous coasts.

Math

Two important math concepts are combinations and permutations. Combinations and permutations are similar in several ways. Both refer to sets of objects that you pick and arrange in order. A set could be the numbers 1 through 9, or available pizza toppings. For combinations and permutations, items are selected from a set. For example, we can select 1-3 from the set 1-9 to count and order. However, combinations and permutations are calculated differently. When we compute a combination, the item order does not matter. A combination of 1, 2, 3 is the same as the combination of 3, 2, 1. Another example of a combination is picking pizza toppings. Suppose you pick three toppings: cheese, pepperoni, and sausage. You can also say that you pick sausage, pepperoni, and cheese. Here you have a combination of three things in two different orders. But the pizzas you get are the same because the order doesn't matter. However, order does matter when we compute a permutation. 1, 2, 3 and 3, 2, 1 are different permutations of these three numbers. In permutations different orders of items have different meanings. Imagine you can pick only one for lunch: pizza, pasta, or rice. You say pizza is your favorite and rice is your least favorite. So your order of preference is: pizza, pasta, and rice. If pizza runs out, the waiter will give you pasta and not rice. But your friend may have a different order of preference. Your friend's order could be: rice, pasta, and pizza. So two orders of the same items mean something quite different. Permutation allows us to count all the possible orders of items. Given three numbers 1, 2, 3, we can derive 6 permutations. These include 1,2,3 / 1,3,2 / 2,1,3 / 2,3,1 / 3,1,2 / 3,2,1. These sequences in different orders are different permutations.

GPS

Global Positioning System (GPS) is a system that helps us navigate. GPS is a system of 24 or more satellites in space. These satellites orbit at about 12,000 miles above the Earth. Different satellites orbit the Earth in different locations. They circle the Earth along 1 of 6 orbits continuously. They send information to a GPS receiver on Earth. The information is transmitted across space via radio signals. Radio signals travel through space like sound waves through a canyon. Imagine you and your friend are at different sides of a canyon. You shout to your friend and she hears you after a short delay. This delay is the time that sound waves need to reach the other side. Similarly, the satellite in space sends a radio signal at one time. After a delay the radio signal arrives at the GPS receiver on Earth. The receiver records the precise time when the radio signal arrives. It then calculates the difference between these two times. This time difference is the travel time of the radio signal. The GPS uses this travel time to figure out how far the satellite is. It uses the formula "distance = time (T) x rate of transmission (C)".T is the travel time of the radio signal. C is the speed of light, more than 186,000 miles per second. T x C calculates the distance between the receiver and each satellite. Different satellites have different distances from the receiver. This information helps the receiver determine its location on Earth. The precise location is calculated based on geometry of distances. A GPS device that you carry in your car is a small receiver. Radio signals from the satellites are updated as the device moves. At least 4 satellites are involved to pinpoint the device's location. GPS devices provide maps and directions that help people travel.

Electric Circuit

Engineers design electrical circuits to power homes and buildings. Electrical circuits are closed paths that electricity flows through. This means that the entire path must be connected like a loop. Imagine a simple circuit made with a battery and a piece of wire. Now connect each end of the wire to different ends of the battery. Your piece of wire and battery now make a circle or circular path. One end of the battery is positive and the other end negative. Electrons will flow across this circuit through the wire. You have just created a simple electrical circuit. Removing the wire from the battery will stop the flow of electrons. Now imagine that you want to connect the battery to a lightbulb. First the wire is cut in the middle and breaks the circuit. Then a lightbulb is inserted to reconnect the circuit. The electrical circuit is complete again and electrons are flowing. Electricity now flows through the lightbulb, lighting it up. If the circuit is now broken, the lightbulb will go out. You can also add a switch in the circuit to break it or connect it. This allows you to turn on or turn off the lightbulb. A simple electrical circuit contains several parts. These include a source, a path, and a resistor. The source provides the energy to an electrical circuit. In our example above, the source is the battery. Batteries can differ in voltage, the electric potential or force. The path is the closed loop with wires that connect to the source. Electrons flow through the path as electric currents. Electric currents increase with increased voltage. The resistor is any device that reduces the electric current. It creates resistance or impedance in the electrical circuit. In our example above, the resistor is the lightbulb. Electric currents decrease with increased resistance.

E2. Assessment Questions (Note: correct answer keys in boldface letter)

Mars

1) Compared to Earth's day, Mars' day is:
   A. Longer
   B. Shorter
   C. The same

2) Which of the following is true?
   A. Earth is closer to the Sun
   B. Mars is closer to the Sun
   C. Mars and Earth are equally distant from the Sun

3) What effect does a planet's axial tilt have?
   A. It allows planets to have water
   B. It allows planets to have seasons
   C. It allows planets to revolve

4) Like Earth, Mars also has:
   A. Dust storms
   B. Waterspouts
   C. Rain storms

5) The temperature on Mars is:
   A. Warmer than Earth
   B. Colder than Earth
   C. The same as Earth

6) Why is the ability to make oxygen from carbon dioxide important?
   A. It may allow us to create water
   B. It may allow us to create fuel
   C. It may allow us to one day live on Mars

7) Compared to Mars, Earth's gravity is:
   A. Stronger
   B. Weaker
   C. The same

8) Why are similarities between Earth and Mars important?
   A. They help us learn more about Earth
   B. They allow scientists to understand when Mars was formed
   C. They may make human travel to Mars possible

9) The soil on Mars contains approximately how much water?
   A. 1%
   B. 2%
   C. 5%

10) Compared with prior rovers, the rover in the *Mars 2020* mission will:
   A. Contain additional instruments
   B. Be smaller than prior rovers
   C. Have the ability to move underground

Supertanker

1) What is the main problem described in the passage?
   A. Huge ships crashing into whales
   B. Supertankers spilling oil into the ocean
   C. Airplane control towers are unavailable

2) Approximately how much oil can a supertanker hold?
   A. A half-million tons
   B. Two million tons
   C. Three million tons

3) About how large is the average supertanker?
   A. The size of a small town
   B. The size of five football fields
   C. The size of the empire state building

4) Why are supertankers important?
   A. They travel all over the world
   B. They have large cargo areas
   C. They transport most of the world's oil

5) Why is microscopic plant life important:
   A. It produces 70% of the world's oxygen
   B. It provides 70% of food for people.
   C. It helps locate where oil spills occur

6) Which of the following contributes to oil spills by supertankers?
   A. Poor communication from ground control stations
   B. A lack of officers operating the ships
   C. Problems with supertankers' engineering

7) What function do double bottom hulls serve for supertankers?
   A. They provide protection to the supertanker
   B. They power the supertanker
   C. They help steer the supertanker

8) Why do power and steering problems occur with supertankers?
   A. Rain falls heavily during ocean storms
   B. They have only one boiler and propeller
   C. They lack double bottom hulls

9) Which of the following can help to solve the problem of oil spills:
   A. Increase the size of the propeller for each supertanker
   B. Improve training for officers of supertankers
   C. Ban travel of supertankers in stormy months

10) What is one benefit of using ground control stations to improve safety?
   A. They guide supertankers along dangerous coasts
   B. They get rid of dangerous coral reefs
   C. They provide covered docks for supertankers during storms

Math

1) In what way are combinations and permutations similar?
   A. They both deal with order in the same way
   B. They both refer to sets of objects that are selected
   C. They are both calculated in the same way

2) When calculating a combination:
   A. Order is important
   B. Order is not important
   C. Order depends on the type of set

3) Which of the following is a combination of 1, 2, 3?
   A. 2, 4, 6
   B. 4, 5, 6
   C. 3, 2, 1

4) Choosing pizza toppings is an example of a combination because:
   A. The order of toppings changes the pizza
   B. The order of toppings does not change the pizza
   C. The order of toppings depends on the set of toppings

5) Why is order important when calculating a permutation?
   A. Different orders have the same meanings
   B. Different orders have different meanings
   C. Different orders make calculation difficult

6) Which calculation allows you to count all possible orders of items?
   A. Permutation
   B. Combination
   C. Selection

7) How many permutations can be calculated from the numbers 2, 3, 4?
   A. 4
   B. 5
   C. 6

8) Which of the following is a permutation of 3, 4, 5?
   A. 5, 5, 3
   B. 3, 3, 4
   C. 4, 3, 5

9) Sequences in different orders form:
   A. Different combinations
   B. Different permutations
   C. Different selections

10) Which of the following is true about combination and permutation?
   A. Combination uses the same items.
   B. Permutation uses different items.
   C. The same set of items can be either combination or permutation.

GPS

1) How many satellites make up the GPS system?

A. 8 or more
B. 12 or more
C. 24 or more

2) Approximately how many miles above Earth do GPS satellites orbit?

A. 8,000 miles
B. 10,000 miles
C. 12,000 miles

3) Based on the passage, each satellite:

A. Follows 1 orbit
B. Follows 3 orbits
C. Follows 6 orbits

4) Through what type of signal is GPS information sent to GPS receivers?

A. Video signals
B. Radio signals
C. Infrared signals

5) Why is the time difference from send to arrival of a signal important?

A. It allows a GPS device to calculate the distance of a satellite
B. It allows a GPS device to calculate how fast a satellite is moving
C. It allows a GPS device to update its settings

6) In the formula, *T* x *C*, what does *T* represent?

A. Thrust
B. Time
C. Speed

7) The formula *T* x *C* calculates which of the following?

A. Location
B. Speed
C. Distance

8) Satellites orbit the Earth along one of how many orbits?

A. 6
B. 10
C. 14

9) Signals from how many satellites are needed for a GPS device to work?

A. At least 2
B. At least 3
C. At least 4

10) Which of the following information does a GPS device provide?

A. Weather and climate
B. News and reviews
C. Maps and directions

Electric Circuit

1) A closed path in a circuit indicates which of the following?
   A. The path has a disconnect
   B. The entire path is connected
   C. The entire path is not working

2) Which of the following describes a battery?
   A. It has two negative ends
   B. It has two positive ends
   C. It has one positive and one negative end

3) Electrical current refers to which of the following?
   A. Electrons flowing through a circuit
   B. Protons flowing through a circuit
   C. Neutrons flowing through a circuit

4) Which of the following is an example of a simple circuit?
   A. Two wires connected to the positive end of a battery
   B. Two wires connected to the negative end of a battery
   C. One wire connected to each end of a battery

5) Adding a switch to an electrical circuit allows:
   A. The current to change directions
   B. The current to be turned on and off
   C. The current to increase in voltage

6) Which of the following provides energy to an electrical circuit?
   A. The source
   B. The path
   C. The resistor

7) Electrical current decreases as:
   A. Voltage decreases
   B. Voltage increases
   C. Voltage stays the same

8) Changes in the amount of voltage are based on:
   A. Changes in a circuit's source
   B. Changes in the path of a circuit
   C. Changes in electrical potential

9) A battery in a simple electrical circuit serves as:
   A. The source
   B. The path
   C. The resistor

10) The amount of electric current increases as:
   A. Resistance increases
   B. Resistance decreases
   C. Resistance stays the same