

Conventional metaphors in longer passages evoke affective brain response

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Abstract

Conventional metaphorical sentences such as *She's a sweet child* have been found to elicit greater amygdala activation than matched literal sentences (e.g., *She's a kind child*). In the present fMRI study, this finding is strengthened and extended with naturalistic stimuli involving longer passages and a range of conventional metaphors. In particular, a greater number of activation peaks (four) were found in the bilateral amygdala when passages containing conventional metaphors were read than when their matched literal versions were read (a single peak); while the direct contrast between metaphorical and literal passages did not show significant amygdala activation, parametric analysis revealed that BOLD signal changes in the left amygdala correlated with an increase in metaphoricity ratings across all stories. Moreover, while a measure of complexity was positively correlated with an increase in activation of a broad bilateral network mainly involving the temporal lobes, complexity was not predictive of amygdala activity. Thus, the results suggest that amygdala activation is not simply a result of stronger overall activity related to language comprehension, but is more specific to the processing of metaphorical language.

Key words: conventional metaphors, text, discourse, emotion, amygdala, fMRI

Significance statement

This work is the first to show that conventional metaphorical language in naturalistic longer passages that includes a range of metaphors elicits more activation in the amygdala--an area recognized to be involved in emotional processing--than carefully matched literal control passages. We probe this finding with parametric analyses using a measure of syntactic complexity and subjective judgments of metaphoricity. While complexity correlates with more overall bilateral activation of the temporal lobes, it does not correlate with amygdala activation. Instead, amygdala activation correlates with metaphoricity, suggesting that the increase in emotional salience is specific to metaphoricity and is not simply a result of an overall increase in brain activity in regions associated with language comprehension.

Introduction

The use of figurative expressions such as metaphors, idioms, irony, and sarcasm in everyday communication is pervasive (1-3). Metaphors in particular may help us conceptualize abstract concepts in more concrete terms, for example, in “*She is one of the brightest students!*” intelligence is conceptualized as brightness, thus evoking the perceptual domain of vision (4, 5). Bright students can “see things clearly,” and they are neither “dim” nor “in the dark.” Recent neuroimaging evidence of metaphor comprehension and representation has shown recruitment of the primary motor cortex during comprehension of action metaphors, e.g., *to grasp the idea* (6-9), of the primary and secondary gustatory cortices during reading of taste metaphors, e.g., *That was a bitter break up* (10), and of texture-selective regions in the somatosensory cortex during reading of texture metaphors, e.g., *She had a rough day* (11).

Beyond facilitating the comprehension and representation of abstract concepts, there exists research indicating a specific role for metaphors, and figurative language more generally, in conveying and evoking emotion. In particular, when asked to recall autobiographical events, participants used more metaphorical expressions when describing how they felt during an event than when describing what happened during the same event; also, the more emotionally intense the event, the more frequent the use of metaphors (12, 13). Furthermore, idioms are used more frequently when formulating complaints, and even more so in the presence of a non-empathic interlocutor (14, 15). More recent evidence has also shown that the use of metaphors in short narratives makes the reader perceive a higher degree of intimacy between the story characters (16-18) and enhances theory of mind (ToM), i.e., the ability to infer characters’ intentions and mental states (18).

It is important to distinguish conventional metaphors, such as the ones just mentioned (*bitter breakup; rough day*), from novel metaphors such as *The breakup was acidic* or *Her day was jagged with sharp edges*. While conventional metaphors are highly familiar and often go unnoticed, novel

Passages with metaphors are more engaging metaphors are more unusual, noticeable and undoubtedly require analogical processes for their interpretation.

A recent neuroimaging finding from our lab suggests that conventional taste metaphors (e.g., *She looked at him sweetly*) are more emotionally engaging than their literal counterparts (*She looked at him kindly*). This study employed metaphorical and literal sentences that were carefully matched for a range of psycholinguistic and affective features, and rated as highly similar in meaning. Enhanced activation of the anterior portion of the left hippocampus and the left amygdala were found for metaphorical over literal sentences during a silent reading task (10). Activation of the amygdala is associated with fast and automatic processing of evolutionary relevant or contextually salient stimuli (19-22) and its concurrent activation with the hippocampus has been associated with successful retrieval of emotional memories (23). These functional associations suggest that when participants read for comprehension, metaphorical formulations are more emotionally engaging than literal paraphrases.

This idea is supported by a meta-analysis of 23 neuroimaging studies of figurative language that also reported enhanced left amygdala activation for figurative as compared to literal material (24). Furthermore, a study on the translation of English figurative expressions referring to emotions into Spanish found an increase in heart rate in participants who read translations that used metaphorical language when compared to those who read non-metaphorical translations (25). Since heart rate response can be used as a physiological index of emotional experience (26), this finding suggests that the metaphorical formulations somehow conveyed a more engaging message than the literal renditions (25).

At the same time, previous work raises several questions. The Rojo et al. (25) study did not control for the number of words or other psycholinguistic or affective properties between metaphorical and literal stimuli. The Bohrn et al. (24) work was also unable to control for these variables because it was a meta-analysis. Finally, Citron and Goldberg (10) used isolated sentences, creating a somewhat artificial reading experience since reading typically involves a context or at

Passages with metaphors are more engaging than at least a longer passage of text (27, 28); in addition, the stimuli were restricted to metaphors involving words and phrases related to taste, which may be a particularly emotionally engaging domain (29, 30).

Importantly, there is currently little understanding of whether metaphoricity itself leads to more emotional engagement or whether the increased affective response is a by-product of something else. In particular, the processing of even highly conventional metaphorical language is recognized to involve somewhat greater brain activity in the left hemisphere, including temporal and frontal lobes as well as the basal ganglia, i.e., caudate nucleus, globus pallidus, thalamus (10, 31, 32). It is possible that the overall increase in brain activity leads to greater engagement, both emotional and cognitive.

The present study aims to address these issues by carefully controlling length, imageability, explicit emotional valence and arousal, understandability, and overall meaning, while participants read longer passages that were rated as natural and which consisted of several sentences each. Only conventional metaphors were included in order to investigate what happens during the most natural, common reading experiences. Each metaphorical passage included several conventional expressions related to a single conceptual metaphor. For example, in a discussion of prices, the conceptual metaphor More as Up was used in phrases meaning “high,” “rose,” “at the top,” etc. (see Table 2). Unlike the previous study that used only taste metaphors (10), a wide range of conventional metaphors were used to create the stimuli, including More as Up, Goals as Destinations, States as Locations, Mental injuries as Physical injuries, and Acting as Motion. Because each metaphorical passage differed in its conceptual metaphor and how that metaphor was expressed, and because it is difficult to avoid conventional metaphors altogether even in the “literal” passages, we also normed each passage on a numerical scale of metaphoricity. In addition, while the passages in the metaphorical and literal conditions were matched overall in terms of a numerical scale of complexity described in detail below, individual passages differed in their complexity. Thus these continuous variables, metaphoricity and complexity, represent more fine-

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grained measures than the binary distinction between the two conditions: metaphorical and literal. Metaphoricity and complexity are used to investigate possible correlations with activation in the amygdala and in language-relevant networks.

We expect both literal and metaphorical passages to activate a bilateral fronto-temporal network associated with sentence and text comprehension, including the inferior frontal gyri (IFG), the temporal lobes and temporal poles, the dorso-medial prefrontal cortex (dmPFC) and the temporo-parietal junction (TPJ; 33, 34). We expect activation in this general network to increase with greater complexity, since more resources are required for the reading of more complex texts. At the same time, based on previous meta-analyses of figurative language processing, we predict enhanced activation in response to the metaphorical stimuli of the left-dominant fronto-temporal network including the IFG, the temporal cortex, the dmPFC, the anterior cingulate cortex (ACC), and the basal ganglia (24, 31, 32).

Most importantly, based on previous work, we predict that metaphorical materials will elicit enhanced activation of the amygdala when compared with literal materials, thereby confirming the hypothesis that metaphorical formulations are more engaging or salient. If amygdala activation correlates with increasing metaphoricity, and not with complexity, it will support the idea that greater emotional engagement is a result of metaphoricity and is not simply due to greater activation overall.

Method

This study was approved by the Ethics Committee of the Free University of Berlin and is in accord with the guidelines of the American Psychological Association.

Participants

Twenty-five German native speakers from the Berlin area took part in the experiment (21-35 years, *mean age* = 26, *SD* = 4, 15 women). They all had normal or corrected-to-normal vision, and

Passages with metaphors are more engaging no neurological diseases or learning disabilities. Participants were each paid 20€ for their participation, and gave informed consent prior to the experiment. After pre-processing, the data from one male participant were excluded from further analyses because of head movements larger than 3 mm. Of the remaining 24 participants, the demographics were the same as above.

Materials

Thirty-two metaphorical and 32 literal short stories were created. Each metaphorical story contained multiple metaphorical expressions, all of which relied on a common conceptual mapping; for example, in Table 1, the first story is about the economy, and contains several expressions associated with the general metaphor, MORE AS UP: *to go up, to rise, high, top, sinking*.

All stories were extensively normed for a range of psycholinguistic and affective features and a subset of 11 metaphorical stories and their 11 literal counterparts were selected and subsequently used in the experiment. The metaphorical and literal stories were rated as equally imageable, emotionally valenced, arousing, understandable, and natural (all $t_s(10) < 1.88$, *ns*), and they were also rated as very similar in meaning (see Table 2 for descriptive statistics); they were matched in length in letters and words (all $t_s(20) < 0.28$, *ns*). A complexity index was determined by adding the number of subordinate clauses, relative clauses, passive forms, compound nouns, new referents, adverbs and adverbial phrases, conjunctive forms, analytically-formed tenses or infinitive constructions, and marked or low-frequency sentence structures (Table 2); complexity was also not different between metaphorical and literal stimuli ($t(20) < 0.00$ *ns*). As intended, metaphorical stories were rated as significantly higher in figurativeness than literal stories ($t(10) = 7.97$, $p < .001$).

Six yes/no comprehension questions were created in order to ensure that participants paid attention to the task as well as a single filler story, to familiarize participants with the task at the beginning of the experiment.

Table 1. Two of the eleven stories used in the experiment. The original German text is followed by an English translation. Some of the figurative expressions employed do not exist in English; however they are translated literally so the reader can get an idea of the way in which the common, underlying conceptual mapping is realized. Metaphorical expressions and their literal counterparts are underlined.

Conceptual mapping	Example of German metaphorical story, followed by English translation	Example of German literal story, followed by English translation
MORE as UP	<p>Die Wirtschaft in China fing langsam wieder an zu <u>wachsen</u>. Die Einnahmen <u>erhöhten sich</u>, die Preise <u>stiegen</u> und die Ausfuhren waren auf einem <u>Rekordhoch</u>. Auch die chinesischen Aktienkurse waren wieder <u>oben angekommen</u>, die Inflation dagegen <u>sank</u>.</p>	<p>Die Wirtschaft in China fing langsam wieder an, <u>Gewinne zu erzielen</u>. Die Einnahmen <u>verdoppelten</u> sich, die Preise und die Ausfuhren waren <u>rekordverdächtig</u>. Auch die chinesische Aktienkurse war wieder auf einem <u>guten Niveau</u> angekommen, die Inflationsrate dagegen war <u>kleiner</u>.</p>
	<p>China's economy was slowly <u>growing</u> again. Incomes <u>went up</u>, prices <u>rose</u> and exports were at a <u>record high</u>. The Chinese stock exchange had <u>arrived at the top</u> again, while inflation was <u>sinking</u>.</p>	<p>The economy in China slowly began to <u>earn profits again</u>. Incomes <u>doubled</u>, prices <u>increased</u>, and exports were <u>record-breaking</u>. The Chinese stock prices had arrived again at a <u>good</u> level, while the inflation rate was <u>smaller</u>.</p>
RELATIONSHIPS as JOURNEYS	<p>Jenny und Paul hatten auf ihrem gemeinsamen <u>Weg</u> schon viele <u>Meilensteine passiert</u>. Aber jetzt stellte sich ihnen ein großes <u>Hindernis in den Weg</u>: Die Fernbeziehung, die <u>vor ihnen lag</u>. Sie befanden sich in einer <u>Sackgasse</u>. In den nächsten Wochen jedoch fanden sie durch Gespräche einen <u>Ausweg</u>.</p>	<p>Marta und Alex hatten in ihrer gemeinsamen Beziehung schon <u>vielen Wichtiges</u> zusammen <u>erlebt</u>. Aber jetzt hatten sie plötzlich ein großes <u>Problem</u>: Die Fernbeziehung, die <u>bald beginnen würde</u>. <u>Sie wussten nicht, was sie tun sollten</u>. In den nächsten Wochen jedoch fanden sie durch Gespräche <u>eine Lösung</u>.</p>
	<p>Jenny and Paul had already <u>gone through</u> many <u>milestones</u> on their common <u>path</u>. But now, a big <u>obstacle</u> positioned itself <u>in their way</u>: The long-distance relationship that <u>lay ahead of them</u>. They were in a <u>dead-end street</u>. However, in the following weeks they found a <u>way out</u> by talking.</p>	<p>Marta and Alex had already <u>solved</u> many <u>important issues</u> during their <u>relationship</u>. But now, they suddenly had to face a big <u>problem</u>: The long-distance relationship that was about to start. <u>They didn't know what to do about it</u>. However, in the following weeks they found a <u>solution</u> by talking.</p>

Table 2. Descriptive statistics of psycholinguistic and affective variables of stories. Imageability, emotional arousal, understandability, naturalness, figurativeness, and similarity in meaning range from 1 (not at all imageable, arousing, etc.) to 7 (very much). Emotional valence ranges from -3 (very negative), through 0 (neutral) to +3 (very positive).

Variables	Metaphorical stories		Literal stories	
	Mean (SEM)	Min - Max	Mean (SEM)	Min - Max
Imageability	3.95 (0.22)	2.53 - 5.27	3.79 (0.26)	2.53 - 5.13
Emotional valence	0.13 (0.40)	-2.67 - 1.94	0.13 (0.44)	-2.31 - 2.63
Emotional arousal	4.28 (0.28)	3.06 - 6.13	3.89 (0.23)	2.50 - 5.13
Understandability	3.37 (0.21)	2.47 - 4.75	3.29 (0.20)	2.19 - 4.07
Naturalness	4.63 (0.15)	3.80 - 5.64	4.97 (0.16)	3.87 - 5.60
Metaphoricity	3.69 (0.23)	2.06 - 4.88	2.04 (0.13)	1.31 - 2.63
Length in letters	343.27 (31.63)	212.00 - 572.00	331.45 (29.79)	191.00 - 532.00
Length in words	61.09 (5.96)	33.00 - 102.00	57.91 (5.37)	34.00 - 93.00
Syntactic complexity	25.45 (1.63)	13.00 - 32.00	19.45 (1.44)	10.00 - 25.00
Similarity in meaning	5.78 (0.09)	5.33 - 6.27		

Procedure

The experiment was conducted at the Dahlem Institute for the Neuroscience of Emotion (D.I.N.E.) at the Free University of Berlin, and was programmed with Presentation (Neurobehavioral System Inc.). Stimulus order and timings were optimized to maximize the statistical efficiency of the task design by using OPTSEQ2 (35) which created randomized sequences of experimental conditions and null events of varying durations (i.e., jittered). The stimuli were presented in 2 different runs: the first run contained a filler story at the beginning, followed by 11 stories (5 metaphorical, 6 literal or vice versa) and 3 questions, in randomized order; the second run contained the remaining 11 stories and 3 questions.

Participants read written instructions describing the whole experiment, signed the informed consent form and were led into the scanner room. First, the magnitude and phase images of the magnetic field in the scanner were measured (1 minute). Then, prior to acquisition of the functional

Passages with metaphors are more engaging images, the experimenter repeated the task instructions orally, asking participants to silently read sentences for comprehension, to attend to the hash mark strings, and to respond to occasional yes/no questions by pressing one of two buttons with their right index and middle fingers. The first functional scanning (or run) lasted 11 minutes (310 functional volumes acquired), and the second run 10 minutes (285 volumes). After the reading task, a structural image was acquired (5 minutes).

Each stimulus was presented at the center of a computer monitor and projected into fMRI-compatible glasses, in white font on a black background. All stories were presented for 26 seconds, and their related questions for 8 seconds; the ISIs after the stories varied between 15 and 25 seconds, whereas the ISIs after the questions varied between 5 and 11 seconds. During the ISIs, a fixation cross was centrally presented in order to keep participants' gaze and attention focused. Overall, the experiment lasted approximately 1 hour, including preparation, scanning and debriefing.

MRI data acquisition and pre-processing

Magnetic resonance images were acquired by means of a 3-Tesla Tim-Trio scanner (Siemens, Erlangen) equipped with a 12-channel receive RF head coil. At the beginning of the experimental session, magnitude and phase images (field map) were acquired: 37 slices per image; 3-mm thick with a 60° flip angle; voxel size: 3x3x3 mm; FOV 192 mm isotropic voxels without gap; matrix per slice: 64x64 mm; TR 488 ms; 2 TE: 4.92; 7.38 ms; acquisition time 1'05". For functional images, a standard EPI sequence was used, with following parameters: 37 slices, 3-mm thick with a 70° flip angle; voxel size: 3x3x3 mm; FOV 192 mm isotropic voxels without gap; matrix per slice: 64x64 mm; TR 2000 ms; TE 30 ms; acquisition time 8'36". At the end of the experiment, full-brain, T1-weighted structural scans were acquired (MPRAGE sequence): 176 slices, 9° flip angle, voxel size: 1x1x1 mm, FOV 256 mm without gap; matrix per slice: 256x256 mm; TR 1900 ms, TE 2.52 ms, acquisition time 4'26".

Processing of the functional images and statistical analyses were performed using SPM8

Passages with metaphors are more engaging (Welcome Trust Centre, <http://www.fil.ion.ucl.ac.uk/spm>), employing slice timing correction, realign and unwarp (through the creation of a field map) and sequential co-registration to structural T1 images. Structural images were segmented into grey matter, white matter, cerebrospinal fluid (CSF), bone, soft tissue and air/background. Based on the segmented grey and white matter images, a group anatomical template was created with the DARTEL toolbox (Ashburner, 2007). Based on these transformation parameters, the functional images were then iteratively normalized to standard space (Montreal Neurologic Institute, MNI). Subsequently, functional volumes were spatially smoothed with a 6-mm Gaussian kernel to adjust for between-participants anatomical differences.

Statistical analyses

Factorial analyses. A General Linear Model was used in an event-related design. Hemodynamic responses were time-locked to the stimulus onset for the whole duration of each stimulus presentation and convolved with the canonical hemodynamic response function of SPM8. Four separate regressors were used for the first run, including metaphorical stories, literal stories, questions, and an initial filler story; whereas only 3 regressors were used for the fourth run (as no filler story was presented). Finally, 6 head-movement regressors were included in each model.

T-contrasts were defined for each participant and then used for the group analysis, at the whole-brain level: metaphorical stories, literal stories (one-sample *t*-tests), metaphorical > literal stories, literal > metaphorical stories. Furthermore, in order to identify which overlapping regions are significantly activated by both conditions, conjunction analyses were performed by merging the two contrasts ‘metaphorical stories’ and ‘literal stories’. For significance levels, a standard voxel-level threshold of $p < .005$ uncorrected was used, along with a cluster-level threshold, corrected for false discovery rate (FDR) of $p < .05$ (36).

In addition, a priori small-volume correction (SVC) on the amygdala, bilaterally, was applied, based on the Talairach Daemon (TD) Brodmann areas atlas, adapted to MNI coordinates, as implemented in the WFU PickAtlas toolbox (37). For the SVC analyses, a voxel-level threshold

Passages with metaphors are more engaging of $p < .001$ uncorrected was chosen, and family-wise error (FWE) correction was applied at the peak level with a threshold of $p < .05$; the stricter thresholding method is more appropriate for SVC analyses (38).

Parametric analyses: metaphoricity and syntactic complexity. In the first run, a first regressor defined the onsets of all stories (metaphorical and literal), and was followed by a linear parametric regressor with metaphoricity ratings for each story. Additionally, one regressor for questions and one for the filler story were included in the model, and followed by 6 head-movement regressors. In the second run, an identical model except for the absence of the filler story regressor was defined. Two one-sample t -tests were defined for each participant and then used for the group analysis, at the whole brain level: correlation of BOLD signal with increasing metaphoricity ratings as well as with decreasing metaphoricity. For each t -test, SVC correction on the bilateral amygdala was applied, based on the TD Brodmann areas atlas. For syntactic complexity, identical models were defined except that the linear parametric regressor contained complexity values instead of metaphoricity.

Results

Common activations between metaphorical and literal materials

At the whole brain level, both literal and metaphorical passages revealed a common bilateral, fronto-temporo-occipital network of enhanced activations when compared with rest (Appendix A). A conjunction analysis revealed significant areas of overlap between metaphorical and literal stories in a bilateral (left-dominant) network, including inferior and middle frontal gyri (I/MFG), superior frontal gyrus (SFG), focal medial areas including the orbito-frontal cortex (OFC) and the dmPFC, extended pre- and post-central gyri, temporal cortices including the middle and superior temporal gyri (M/STG) and the left temporal pole (TP), and bilateral (non-left-dominant) occipital cortices (Figure 1; Table 3).

Figure 1

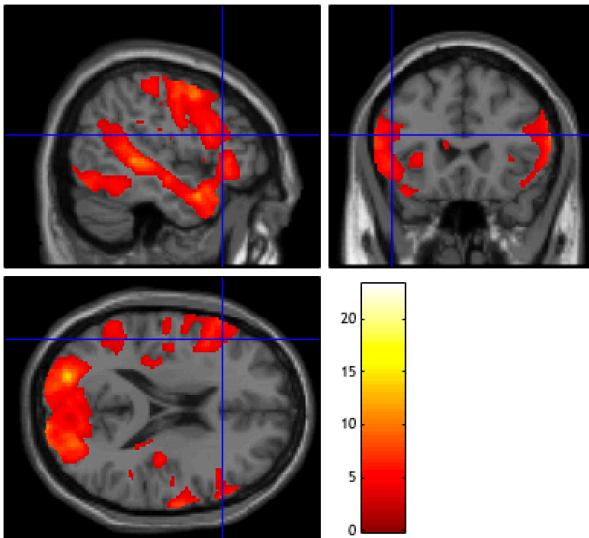


Figure 1. Common regions of significant activation from the conjunction analysis that includes contrasts between metaphorical stories and rest, and literal stories and rest. MNI coordinates: -48 24 19. A significance threshold at the voxel level of $p < .005$ uncorrected was applied, followed by FDR correction at the cluster level.

Table 3. Regions showing significant BOLD signal change in response to a conjunction analysis including the contrasts between metaphorical stories and rest, and literal stories and rest, at the whole-brain level. A significance threshold at the voxel level of $p < .005$ uncorrected was applied, followed by FDR correction at the cluster level. Legend: Hemi. = hemisphere, L = left, R = right; cluster size is in voxels, T = peak t value; X, Y, Z = MNI stereotactic space coordinates.

Broader area	Hemi.	Region	Cluster size	T	X, Y, Z
Conjunction: Metaphorical stories > Rest & Literal stories > Rest					
Frontal lobe	L/R	Straight gyrus	362	5.89	0 48 -21
		Medial frontal gyrus, pars orbitalis		5.13	-2 54 -15
		Medial frontal gyrus, pars orbitalis (BA 10)		4.05	-6 61 -9
Frontal lobe	L	Posterior dorso-medial prefrontal cortex (BA 8)	582	5.38	-10 46 50
		Dorso-media prefrontal cortex (BA 9)		4.76	-9 58 39
		Dorso-media prefrontal cortex (BA 9)		4.40	-12 40 56
Frontal lobe	L/R	Supplementary motor area	2758	8.84	-6 6 59
		Supplementary motor area (BA 6)		7.66	8 9 54
		Supplementary motor area (BA 6)		5.08	-6 4 74
Frontal/Temporal lobe	R	Superior temporal gyrus	7466	9.40	46 -30 3
		Superior temporal pole		8.99	48 14 -19
		Inferior frontal gyrus, pars triangularis (BA 45)		8.35	62 24 17
Parietal lobe	R	Superior parietal lobule	1466	6.03	24 -56 51
		Superior parietal lobule		5.97	27 -60 57
		Inferior parietal lobule		4.31	33 -45 51
Occipital lobe	L/R	Calcarine fissure	85610	23.14	8 -86 -1
		Lingual gyrus		20.29	16 -87 -4
		Lingual gyrus		17.63	-3 -77 -1

Amygdala activation for metaphorical and literal materials

Application of the small-volume correction revealed that the left amygdala was active to some extent during the reading of both metaphorical and literal stories. At the same time, the metaphorical stories activated a larger portion of the amygdala, bilaterally. In particular, the analysis revealed enhanced bilateral amygdala activation in 4 peaks for the metaphorical passages and only one significant peak in the left amygdala for literal passages when compared with rest (Table 4). No amygdala activation was detected when the SVC was applied to the direct contrast between metaphorical and literal stories. Nevertheless, when metaphoricity was analysed parametrically across all stories, i.e., when a more fine-grained measure for each stimulus was used rather than a categorization into two groups, its increase led to significantly enhanced left amygdala activation (Table 4).

Table 4. Peaks showing significant BOLD signal change in the SVC analyses. A significance threshold at the voxel level of $p < .001$ uncorrected was applied, followed by FWE correction at the peak level. Legend: Hemi. = hemisphere, L = left, R = right, T = peak t value; X, Y, Z = MNI stereotactic space coordinates. The last two peaks in italics and grey background were marginally

significant ($p = 0.060$).

Hemi.	T	X, Y, Z
Metaphorical stories > Rest		
L	6.91	-21 -5 -15
L	5.16	-28 -6 -22
R	4.83	21 -3 -13
R	4.50	30 -5 -22
Literal stories > Rest		
L	5.23	-21 -8 -16
Increase in metaphoricity		
L	4.01	-26 0 -22
R	3.70	27 -3 -19
L	3.70	-24 -3 -16

Differences between metaphorical and literal materials

Wide-spread, predominantly left-lateralized activation was found for the contrast metaphorical > literal (Figure 2; Table 5), including IFG, pars triangularis and orbitalis (BA 47), the left and left posterior dmPFC (BA 9 and 8, respectively), the right pre-central gyrus, the left temporal cortex, including I/M/STG and TP and extended into the left anterior insular cortex (AIC), the anterior and middle cingulate cortex (A/MCC) bilaterally, the left hippocampus, bilateral parietal regions including the inferior and superior parietal lobules (I/SPL) and angular gyri, bilateral visual areas including the fusiform and lingual gyri, the cunei and the pre-cunei, basal ganglia including the caudate nuclei and thalami, and the right cerebellum.

Parametric analysis: Metaphoricity. By increasing metaphoricity, a significantly enhanced, mainly left-lateralized network of activations very similar to the one just described appeared (refer to Appendix B for specific voxels). No regions of significantly enhanced BOLD response were found when decreasing metaphoricity. Crucially, as previously mentioned, after SVC one peak in the left amygdala was found to be significantly active and another two peaks in left and right amygdala were marginally significant.

Figure 2.

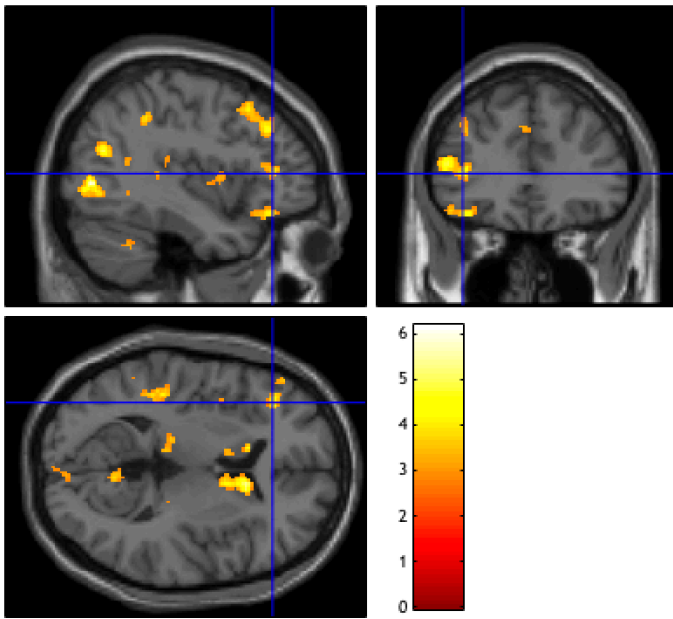


Figure 2. Regions of significant activation resulting from the contrast metaphorical > literal stories (MNI -39 34 8): Involvement of several left inferior frontal clusters, the anterior insula and parietal and visual areas are visible in the upper left picture; left frontal clusters and the ACC are visible in the upper right picture; the caudate nuclei are clearly visible at the center of the left lower picture. A significance threshold at the voxel level of $p < .005$ uncorrected was applied, followed by FDR correction at the cluster level.

Table 5. Regions showing significant BOLD signal change for the contrast between metaphorical stories and literal stories, at the whole-brain level. A significance threshold at the voxel level of $p < .005$ uncorrected was applied, followed by FDR correction at the cluster level. Legend: Hemi. = hemisphere, L = left, R = right; cluster size is in voxels, T = peak t value; X, Y, Z = MNI stereotactic space coordinates.

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Broader area	Hemi.	Region	Cluster size	T	X, Y, Z
Metaphorical stories > Literal stories					
Frontal lobe	L	Inferior frontal gyrus, pars triangularis	524	4.79	-48 34 14
		Inferior frontal gyrus, pars triangularis		4.48	-39 34 8
		Inferior frontal gyrus, pars triangularis		4.37	-52 40 11
Frontal lobe	L	Inferior frontal gyrus, pars orbitalis	279	4.59	-36 34 -18
		Inferior frontal gyrus, pars orbitalis (BA 47)		4.07	-44 30 -13
		Inferior frontal gyrus, pars orbitalis		2.93	-48 31 -6
Frontal lobe	L	Middle frontal gyrus	585	4.59	-39 31 35
		Middle frontal gyrus (BA 8)		4.02	-39 19 47
		Middle frontal gyrus (BA 8)		3.65	-48 21 42
Frontal lobe	L	Medial superior frontal gyrus	334	3.81	-2 58 36
		Medial superior frontal gyrus		3.70	0 52 27
		Medial superior frontal gyrus (BA 9)		3.67	-3 40 32
Pericentral cortex	R	-	365	4.49	16 -24 59
		Pre-central gyrus		4.45	14 -29 66
		Paracentral lobule		3.70	8 -29 75
Temporal lobe	L	Superior temporal pole	642	4.75	-48 12 -15
		Superior temporal pole		3.95	-57 9 -7
		Anterior insular cortex		3.65	-42 4 5
Temporal lobe	L	Superior temporal gyrus (BA 41)	431	5.19	-45 -30 5
		Superior temporal gyrus		3.57	-45 -42 6
		Insula		3.48	-40 -30 17
Temporal lobe	L	Inferior temporal gyrus (BA 37)	362	4.44	-56 -59 -8
		Middle temporal gyrus		3.72	-50 -56 2
		Inferior temporal gyrus (BA 19)		3.38	-56 -68 -6
Temporal lobe	L	Middle temporal gyrus	1262	5.87	-44 -51 18
		Middle temporal gyrus		5.28	-40 -68 20
		Angular gyrus		4.86	-46 -71 27
Medial temporal cortex	L/R	Middle cingulate cortex (BA 24)	285	4.02	-3 -3 32
		Middle cingulate cortex (BA 24)		3.88	6 -2 36
		Middle cingulate cortex (BA 24)		3.37	3 -8 45
Medial temporal cortex	L	Thalamus	335	5.41	-16 -30 2
		Hippocampus		4.03	-24 -36 2
		Hippocampus		3.83	-30 -36 -6
Basal ganglia	R	Pulvinar (thalamus)	269	4.58	18 -27 14
		Ventral lateral nucleus (thalamus)		4.19	14 -18 17
Basal ganglia	L	Caudate nucleus	281	5.00	-12 18 6
		Caudate nucleus		3.93	-14 4 15
		Caudate nucleus		3.65	-9 7 8
Basal ganglia	R	Caudate nucleus	919	5.73	8 9 0
		Caudate nucleus		5.26	10 18 8
		Caudate nucleus		5.11	9 6 11
Parietal lobe	L	Inferior parietal lobule	668	4.59	-26 -60 39
		Superior parietal lobule		4.31	-24 -72 42
		Superior occipital gyrus		3.53	-16 -78 44
Parietal lobe	L	Inferior parietal lobule (BA 40)	428	4.47	-48 -35 41
		Inferior parietal lobule (BA 40)		4.24	-46 -45 46
		-		4.13	-33 -50 33
Parietal lobe	L	Superior parietal lobule	271	3.60	-21 -65 62
		Pre-cuneus (BA 7)		3.40	-12 -60 64
		Pre-cuneus		3.26	-3 -60 68
Occipital lobe	L	Superior frontal gyrus	1128	5.16	-24 -41 -24
		Fusiform gyrus		4.77	-45 -56 -19
		Fusiform gyrus		4.28	-33 -51 -21
Parietal lobe	R	Superior parietal lobule (BA 7)	316	4.04	21 -77 52
		Superior parietal lobule		3.71	32 -74 52
		Angular gyrus		3.54	36 -69 40
Occipital lobe	L	Lingual gyrus	983	6.15	-26 -60 -2
		Fusiform gyrus		5.50	-30 -60 -10
		Lingual gyrus		4.96	-10 -66 -9
Occipital lobe	L	Middle occipital gyrus	278	5.81	-39 -75 2
Occipital lobe	R	Fusiform gyrus	572	5.40	46 -54 -22
		Cerebellum		5.30	33 -38 -28
		Fusiform gyrus (BA 37)		4.43	40 -44 -22
Occipital lobe	R	Cuneus	2668	5.26	3 -78 20
		Cuneus (BA 19)		4.64	6 -84 32
		Lingual gyrus		4.60	8 -51 0
Occipital lobe, Cerebellum	R	Lingual gyrus	322	4.43	0 -86 -13
		Cerebellum		3.90	8 -62 -9
		Vermis (cerebellum)		3.75	2 -68 -9

Syntactic complexity

By increasing syntactic complexity, we found a broad bilateral network of brain regions associated with language processing. More specifically, the larger clusters of significant activation involved both temporal lobes extensively (see Figure 3a and Appendix C).

A decrease in syntactic complexity was associated with significant activations of regions associated with the default mode network (39), with the largest clusters in the parietal cortex bilaterally, i.e., IPL, SPL, angular gyrus (Figure 3b), and some involvement of the inferior frontal regions (refer to Appendix C for details).

Figure 3a.

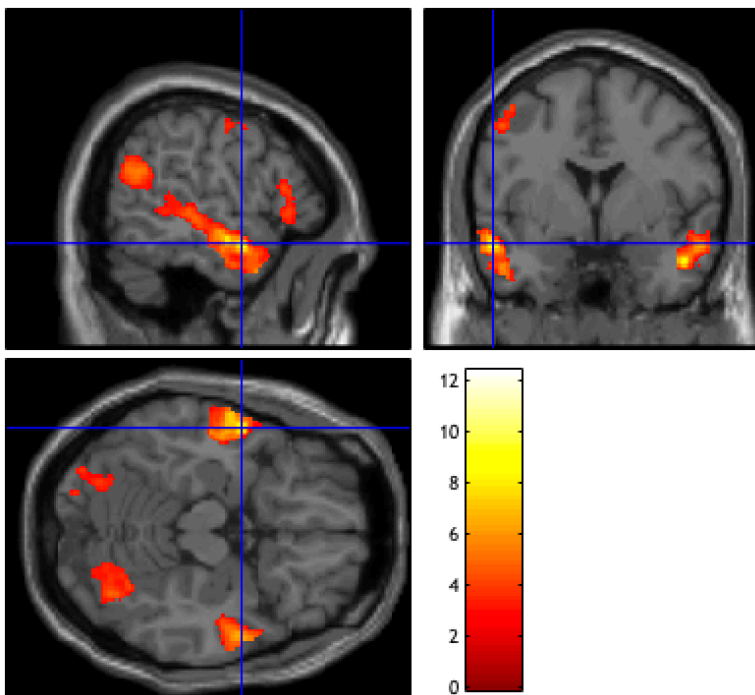


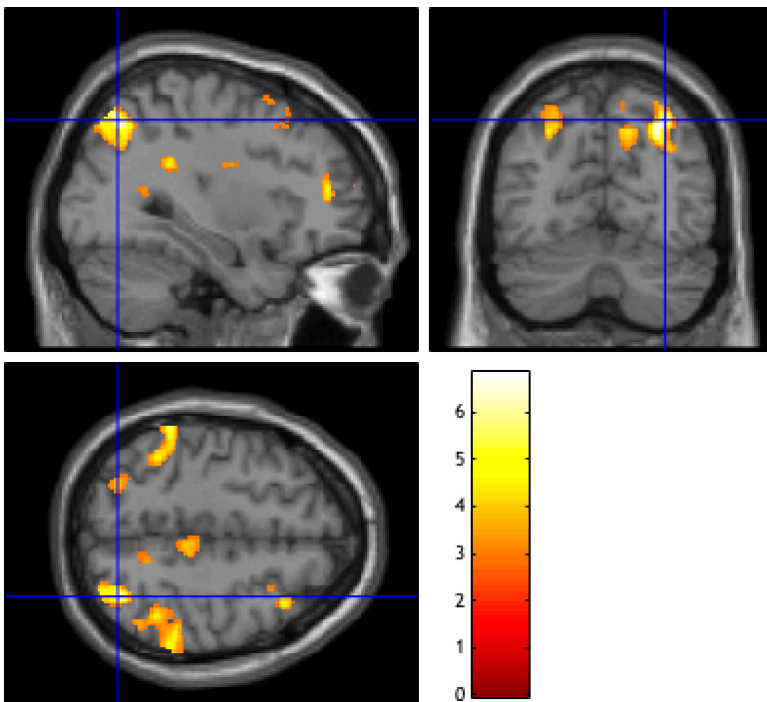
Figure 3b.

Figure 3. Regions of significant BOLD signal response change associated with: **(a)** increasing syntactic complexity including extensive activation of the superior middle temporal lobes (left MTG, MNI -54 0 -16); **(b)** decreasing syntactic complexity including the TPJ and superior occipital gyri bilaterally (right angular gyrus, MNI 33 -68 50). For both images, a significance threshold at the voxel level of $p < .005$ uncorrected was applied, followed by FDR correction at the cluster level.

Discussion

The use of longer passages allowed us to test the hypothesis that conventional metaphors would evoke stronger emotional engagement even in a naturalist reading situation, in which metaphorical and non-metaphorical stimuli were carefully matched in naturalness, understandability, imageability, length, complexity, and explicit judgments of emotional valence and arousal. The metaphorical stimuli and the non-metaphorical stimuli were also rated as highly similar in meaning. In line with the hypothesis, reading metaphorical passages elicited significantly

Passages with metaphors are more engaging enhanced activation of the amygdala. That is, while both metaphorical and literal stories elicited enhanced left amygdala activation when compared to rest, the former activated more peaks, in both left and right amygdala, compared to the latter. This finding is consistent with previous results that had investigated only taste metaphors in isolated sentences (10), in that results corroborate the hypothesis of heightened processing of metaphorical than literal materials, an indication of stronger emotional engagement. That is, activation of the amygdala is associated with implicit processing of emotionally intense or contextually salient stimuli (19-21, 40). However, in a direct contrast between metaphorical and literal stories, no amygdala activation was detected. This may be due to the fact that the literal stories themselves were emotionally engaging, as their content often touched upon emotional topics. Nevertheless, higher metaphoricity ratings across all stories correlated with higher activation in the left amygdala. Hence, these findings confirm stronger emotional engagement is elicited by conventional metaphorical materials than by their literal counterparts.

Reading both metaphorical and literal stories also activated a bilateral fronto-temporo-occipital network of brain regions functionally associated with text comprehension. The more classical language-related areas are the IFG (including Broca's area), associated with grammatical processing, parsing (41), pronoun resolution and more generally the establishment of cohesion during text comprehension (33, 42), and the posterior STG (Wernicke's area), associated with language comprehension and sound-to-meaning mapping (43). Furthermore, the temporal lobes represent the central loci of our lexical, semantic, and conceptual representations (43-45); more specifically, the anterior and posterior STG are associated with integration and interpretation processes (33), as well as building of a sentence structure and compositional processes (41, 46), whereas the anterior temporal lobe (aTL, including the TP) is associated with the updating of the mental representation of a text (i.e., the situation model), which includes increasing integration demand, time shifts and violations of situation model aspects (33, 47, 48). In addition, medial regions such as the dmPFC, posterior cingulate cortex (PCC), and the precuneus are associated with strategic inference processes (used for example to establish coherence during text reading) and

Passages with metaphors are more engaging ToM, i.e., the attribution of a mental state to others, such as the protagonists of a story (34, 49-51). Finally, the TPJ, including SPL, IPL, and the angular gyrus, has been associated with the initial set up of a situation model (52), and also with ToM (50, 51). These medial regions as well as the TPJ are also part of the default network; i.e., they are associated with reflections on internal mental states and mind wandering, rather than the processing of external stimuli (39, 53). These two broader functions, i.e., inference and ToM on one hand, and mind wandering and internal reflection on the other, are compatible with each other and implemented in the same neural network (54).

Interestingly, when contrasting metaphorical versus literal stories, and when increasing metaphoricity, we found greater activation of a similar, but more strongly left-lateralized network associated with affective responses as well as text and discourse comprehension. In particular, we could identify a left-lateralized circuit of activations including the left IFG, dmPFC, AIC, A/MCC, TP, and parietal cortex, which is typically active during tasks that involve executive functions such as problem solving, working memory, and inhibition (e.g., 55, 56, 57). Furthermore, some of these regions as well as other regions that were significantly active are typically associated with text comprehension; i.e., more extended portions of the left IFG, ITG, MTG, STG, the TP, dmPFC, precuneus, the right pre-central gyrus, and the TPJ bilaterally, overall indexing more demanding processes of cohesion and coherence building, inferences, semantic integration and interpretation, and ToM (33, 58). Meta-analyses of figurative language have identified similar networks of enhanced activations for figurative or more specifically metaphorical language compared to literal language (24, 31, 32, but cf. 59)¹. Thus it may be that the increase in these regions for metaphorical passages results from a greater demand for coherence establishment across metaphorical expressions contained within the same story, broader semantic associations, and increased memory load (e.g., 60, 61). The thalamus contributes to lexical and semantic retrieval (62), is more

¹ In a study that found *less* activation in the aSTG for figurative over literal passages (59), both types of stimuli were presented as poetry (e.g., *I look at him / And see my past emerge / From his countenance / That refuses to grow up.* vs. *I look at him / And examine his young face / From his photo album / That is next to me*). Since the stimuli used were not equated for content, the increased response in an area related to text comprehension may have been due to the difficulty associated with understanding why the literal stimuli, being concrete and straightforward, were presented *as poetry*.

Passages with metaphors are more engaging generally involved in attention and executive functions during language processing (63) and its enhanced activation has been previously reported in response to figurative and conventional metaphorical language compared to literal language (24, 32).

Certain aspects of the differential activation evoked in the comparison of metaphorical > literal stories may be related to emotional engagement. The anterior insular and cingulate cortices (as well as the amygdala) are involved in emotional salience monitoring; i.e., they detect salient environmental changes or stimuli regardless of the modality of the task employed (20, 64). The AIC is functionally connected with the ACC and the MCC (65), and while the former is more strongly involved in emotional salience (66), the latter two are involved in more general salience detection during cognitively demanding tasks (67). The metaphorical formulations may be particularly salient stimuli since they activate richer and multiple semantic representations in comparison with their literal counterparts.

Enhanced activation of the left hippocampus is in line with our previous findings on taste metaphors (10); its activation is usually associated with encoding and retrieval of emotional memories (23, 68, 69) and has also been reported in response to emotion words during lexical access (70). The caudate nucleus is associated with prosodic and rhythmic processing during language comprehension and production (71, 72), and also with feelings of reward (73) in response to aesthetically pleasing stimuli (74, 75), including familiar proverbs rated as increasingly beautiful (75). Finally, a role for the right cerebellum in linguistic and affective processes has been established (76).

The temporal lobes are not only the central locus of our semantic representations (45), but they are also associated with integration and interpretation processes (in the STG; 33), building of a sentence structure and compositional processes (also in the STG; 41), updating of the mental representation of a text, i.e., the situation model, in the aTL (including the TP) as well as increasing integration demand, time shifts and violations of situation model aspects (33, 47, 48). It is also well-known that processing complex language leads to recruitment of the right hemisphere as well as the

left as found here (e.g., 77).

Aiming to better understand whether the stronger emotional engagement in response to metaphorical stories could be an epiphenomenon of greater overall activation related to language comprehension, we examined BOLD signal changes in response to increasing grammatical complexity. As expected, strongly bilateral involvement of the temporal cortices was found, as these areas are associated with integration and interpretation processes.

However, and most interestingly, in contrast to the network activated in response to metaphorical > literal stories, the complexity measure did not correlate with activation of the salience network at the whole-brain level, i.e., A/MCC, AIC, amygdala, nor other areas associated with affective processing such as the hippocampus, parahippocampal gyrus, or caudate nucleus. Most importantly, the small-volume correction revealed no activation of the amygdala with increasing complexity either. This suggests that the emotional engagement associated with reading short stories and metaphorical ones in particular cannot be simply associated with an overall enhanced activation of the language-related network.

We propose two possible explanations for the effect that conventional metaphors elicit a greater brain response in the amygdala and other areas involved in emotional processing. First of all, the metaphorical grounding of abstract concepts into more concrete concepts, which can be linked to sensory-motor functions (4, 78), may elicit more vivid representations, which may in turn automatically engage the reader at the physiological level. An alternative, although not mutually exclusive explanation is that metaphors elicit richer semantic representations because they activate attributes belonging to both the source and the target concepts, e.g., stating that someone had “a heavenly coffee” may convey a meaning richer in associations than “a delicious coffee”, as it may activate attributes related to heaven and ecstatic experiences as well as taste. Such enriched representations may in turn lead to a stronger cognitive and emotional engagement.

One limitation of the present study is that we were able to replicate the amygdala finding using small volume correction only in the contrasts between each experimental condition and rest,

Passages with metaphors are more engaging as well as in response to increasing metaphoricity ratings, but not in the direct contrast between metaphorical and literal materials. This may be because the literal stories were also emotionally engaging, certainly more than simple, isolated sentences as the ones employed in our previous study (Citron & Goldberg 2014). A second limitation is that our measure of complexity was rather coarse-grained since it combined various contributing factors into a single number. Reassuringly, however, this measure was found to correlate positively with broad bilateral temporal activation, suggesting that it indeed captures at least a type of complexity related to text comprehension.

Conclusion

In conclusion, the present results support the idea that conventional metaphors engage the reader more at the emotional level by generalizing previous results to a more natural reading context involving a range of conceptual metaphors, while controlling for other relevant psycholinguistic variables. Metaphorical and literal materials elicited activation of an overlapping bilateral fronto-temporo-occipital network of regions typically active during sentence and text comprehension. This is expected, given the high similarity in meaning between the two types of materials and the high conventionality of our metaphorical expressions.

At the same time, we found enhanced activation of a left-dominant fronto-temporal network in the case of the metaphorical stories, in areas associated with the detection of emotional or salient stimuli during cognitively demanding tasks, as well as executive functions, text comprehension, and theory of mind. This is consistent with previous meta-analyses of figurative language processing. Of particular interest is the finding that, while a broad bilateral network of activation correlated with a measure of complexity, amygdala activation did not. This last finding undermines the idea that the greater emotion-related response is simply a consequence of greater activity overall for conventional metaphorical processing, and suggests that metaphorical language *captures* our emotions (is more evocative) for reasons related directly to metaphoricity.

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Specific contributions of each author

FMMC and AEG conceived and designed the experiment, and wrote up the manuscript together. FMMC designed the more technical aspects of the experiment, programmed the experiment, analyzed and interpreted the data. NM created the linguistic stimuli, collected norms for subjective variables through online questionnaires, and tested participants in the MRI scanner. JG selected and matched the linguistic stimuli statistically, contributed to programming the experiment, and tested participants in the MRI scanner.

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Passages with metaphors are more engaging

Appendix A. Regions showing significant BOLD signal change for the contrasts between metaphorical stories and rest, and literal stories and rest, at the whole-brain level. A significance threshold at the voxel level of $p < .005$ uncorrected was applied, followed by FDR correction at the cluster level. Legend: Hemi. = hemisphere, L = left, R = right; cluster size is in voxels, T = peak t value; X, Y, Z = MNI stereotactic space coordinates.

Broader area	Hemi.	Region	Cluster size	T	X, Y, Z
Metaphorical stories > Rest					
Frontal lobe	R	Medial frontal gyrus, pars orbitalis	510	7.81	2 54 -15
		Straight gyrus		6.10	0 48 -21
Frontal lobe	L	Medial frontal gyrus, pars orbitalis (BA 10)	1472	5.30	-4 61 -9
	L	Dorso-medial prefrontal cortex		6.80	-10 46 50
		Dorso-medial prefrontal cortex		5.84	-6 61 35
		Superior frontal gyrus (BA 8)		5.36	-12 40 56
Frontal lobe/Basal ganglia	R	Frontal lobe	419	4.86	32 30 0
		Putamen		3.85	26 15 6
		Putamen		3.42	28 10 0
Occipital lobe	L	-	124330	25.36	-26 -26 -3
	R	Calcarine fissure		24.34	9 -84 0
		Lingual gyrus (BA 18)		20.42	15 -81 -8
Literal stories > Rest					
Frontal lobe	L	Dorso-medial prefrontal cortex	522	5.31	-9 48 50
		Dorso-medial prefrontal cortex		4.55	-8 61 35
		Superior frontal gyrus (BA 8)		4.38	-12 40 56
Frontal lobe	R	Straight gyrus	319	6.14	0 48 -21
	L	Medial frontal gyrus, pars opercularis		4.84	-3 54 -15
Frontal lobe		Medial frontal gyrus, pars opercularis (BA 10)	2776	3.85	-6 61 -9
	L	Supplementary motor area (BA 6)		8.66	-8 6 59
	R	Supplementary motor area (BA 6)		8.27	9 7 54
	L	Supplementary motor area		6.40	-8 13 50
Medial temporal cortex/Basal ganglia	R	Insula (BA 13)	261	6.28	34 -20 20
		Putamen		3.18	30 -15 11
		Insula		2.99	40 -8 20
Parietal lobe	R	Superior parietal lobule	1413	6.36	24 -56 51
		Superior parietal lobule		5.88	27 -62 57
		Angular gyrus		5.42	27 -57 44
Occipital lobe	R	Calcarine fissure	92140	22.56	8 -86 -2
		Lingual gyrus		20.67	18 -89 -6
		Lingual gyrus (BA 18)		19.93	15 -81 -8

Appendix B. Regions showing significant BOLD signal change correlated with increasing metaphoricity, at the whole-brain level. A significance threshold at the voxel level of $p < .005$ uncorrected was applied, followed by FDR correction at the cluster level. Legend: Hemi. = hemisphere, L = left, R = right; cluster size is in voxels, T = peak t value; X, Y, Z = MNI stereotactic space coordinates.

Broader area	Hemi.	Region	Cluster size	T	X, Y, Z
Increase in metaphoricity					
Frontal lobe	L	Inferior frontal gyrus, pars triangularis	1313	5.30	-50 33 14
		Inferior frontal gyrus, pars orbitalis		4.23	-51 33 -6
		Inferior frontal gyrus, pars triangularis		4.10	-50 40 -1
Frontal lobe	R	Inferior frontal gyrus, pars orbitalis (BA 47)	432	6.15	50 49 -6
		Middle frontal gyrus		5.27	39 43 -1
		Middle frontal gyrus, pars orbitalis		3.95	36 42 -10
Frontal lobe	L	Superior frontal gyrus	1623	5.71	-15 42 41
		Superior frontal gyrus		5.52	-14 49 30
		Dorso-medial prefrontal cortex		4.47	-2 61 21
Frontal lobe	L	Middle frontal gyrus (BA 9)	770	4.27	-39 28 38
		Middle frontal gyrus (BA 8)		4.20	-48 22 42
		Middle frontal gyrus		3.89	-39 16 44
Temporal lobe	L	Middle temporal gyrus	1976	5.31	-44 -51 18
		Middle temporal gyrus		5.05	-42 -69 22
		Angular gyrus		4.69	-51 -54 24
Temporal lobe	L	Middle temporal gyrus	501	4.17	-52 -29 -6
		Middle temporal gyrus		4.07	-57 -21 -7
		Middle temporal gyrus		3.47	-58 -20 -16
Temporal lobe	L	Superior temporal pole	455	4.16	-57 9 -7
		Superior temporal pole		4.11	-48 13 -15
		Superior temporal pole (BA 22)		3.92	-51 3 -1
Temporal lobe	R	Cerebellum	517	4.90	33 -38 -31
		Inferior temporal gyrus		4.52	45 -54 -24
		Parahippocampal gyrus		4.19	30 -30 -18
Pericentral cortex	R	-	502	4.18	15 -26 60
		Paracentral lobule		4.06	8 -26 75
		Pre-central gyrus		3.88	16 -30 68
Parietal lobe	R	Inferior parietal lobule (BA 40)	530	4.06	39 -53 52
		Angular gyrus		3.37	52 -50 36
		Supramarginal gyrus (BA 40)		3.32	48 -44 44
Basal ganglia	L/R	Caudate nucleus	1649	6.06	8 15 8
		Caudate nucleus		4.98	-12 18 5
		Caudate nucleus		4.89	-9 9 11
Occipital lobe	L	Superior occipital gyrus (BA 7)	414	3.83	-18 -83 27
		Superior parietal lobule (BA 7)		3.75	-24 -75 44
		Cuneus (BA 19)		3.70	-10 -87 38
Occipital lobe	L/R	Cerebellum (vermis)	1216	4.66	4 -54 -6
		Calcarine fissure		4.28	-9 -60 10
		Lingual gyrus		4.25	10 -54 2
Occipital lobe	R	Calcarine fissure (BA 18)	3143	5.99	6 -74 16
		Cuneus		5.65	9 -86 33
		Cuneus (BA 19)		4.94	14 -92 21
Cerebellum	L	Cerebellum	562	4.39	-27 -60 -28
		Cerebellum		3.76	-42 -53 -36
		Cerebellum		3.67	-42 -62 -28

Passages with metaphors are more engaging

Appendix C. Regions showing significant BOLD signal change correlated with increasing and decreasing syntactic complexity, at the whole-brain level. A significance threshold at the voxel level of $p < .005$ uncorrected was applied, followed by FDR correction at the cluster level. Legend: Hemi. = hemisphere, L = left, R = right; cluster size is in voxels, T = peak t value; X, Y, Z = MNI stereotactic space coordinates.

Passages with metaphors are more engaging

Broader area	Hemi.	Region	Cluster size	T	X, Y, Z
Increase in syntactic complexity					
Frontal lobe	L	Inferior frontal gyrus, pars triangularis	625	4.89	-51 27 3
		Inferior frontal gyrus, pars triangularis		4.17	-54 22 12
		Inferior frontal gyrus, pars opercularis (BA 45)		3.52	-48 16 15
Frontal lobe	L	Middle temporal gyrus	6276	9.87	-62 -5 -13
		Middle temporal gyrus		9.07	-54 -0 -16
		Temporal pole		8.72	-48 7 -31
Temporal lobe	R	Middle temporal gyrus (BA 21)	3008	9.59	50 -2 -27
		Temporal pole (BA 38)		7.73	54 12 -22
		Middle temporal gyrus (BA 21)		6.59	57 -2 -18
Temporal lobe	R	Angular gyrus (BA 40)	311	4.09	56 -51 24
		Angular gyrus		3.64	45 -54 30
		Middle temporal gyrus (BA 22)		3.38	64 -54 16
Pericentral cortex	L	Pre-central gyrus (BA 6)	490	5.11	-50 3 47
		Post-central gyrus (BA 4)		3.93	-52 -8 47
Medial temporal cortex	L/R	Middle cingulate cortex (BA 31)	531	4.91	-9 -48 34
		Precuneus (BA 7)		4.07	-4 -54 40
		Precuneus (BA 7)		3.11	4 -59 34
Occipital lobe	L/R	Calcarine fissure (BA 30)	12055	12.32	3 -74 6
		Calcarine fissure		10.12	0 -95 9
		Calcarine fissure (BA 17)		9.33	-4 -90 2
Decrease in syntactic complexity					
Frontal lobe	L	Inferior frontal gyrus, pars orbitalis	266	4.88	-28 34 -10
Frontal lobe	L	Middle frontal gyrus	865	4.21	-44 33 32
		Inferior frontal gyrus, pars triangularis		4.00	-38 40 12
		Middle frontal gyrus		3.69	-46 48 17
Frontal lobe	R	Middle frontal gyrus (BA 8)	369	5.76	36 18 47
		Superior frontal gyrus (BA 6)		4.70	28 19 59
		Middle frontal gyrus		3.70	28 15 41
Frontal lobe	R	Middle frontal gyrus	808	5.64	34 45 15
		Middle frontal gyrus		5.00	40 37 20
		Middle frontal gyrus		3.22	39 57 11
Temporal lobe	L	Inferior temporal gyrus (BA 37)	563	5.93	-51 -57 -6
		Inferior temporal gyrus		5.15	-54 -51 -13
Temporal lobe	R	Inferior temporal gyrus	263	4.73	51 -48 -8
		-		3.59	45 -41 -10
		Middle temporal gyrus		3.31	58 -39 -12
Parietal lobe	L	Inferior parietal lobule	1912	6.51	-44 -45 44
		Inferior parietal lobule		5.69	-57 -41 50
		Superior occipital gyrus		4.67	-28 -66 44
Parietal lobe	R	Precuneus (BA 7)	460	5.43	6 -51 56
		Superior parietal lobule		3.73	15 -60 58
Parietal lobe	R	-	3495	5.15	32 -42 26
		-		5.12	39 -36 30
		Inferior parietal lobule (BA 40)		5.12	39 -45 40
Occipital lobe	R	Angular gyrus (BA 7)	1335	6.81	33 -68 50
		Superior occipital gyrus		6.47	28 -66 42
		Precuneus		4.56	15 -71 44