Neural Correlates of Lyrical Improvisation: An fMRI Study of Freestyle Rap

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The neural correlates of creativity are poorly understood. Freestyle rap provides a unique opportunity to study spontaneous lyrical improvisation, a multidimensional form of creativity at the interface of music and language. Here we use functional magnetic resonance imaging to characterize this process. Task contrast analyses indicate that improvised performance is characterized by dissociated activity in medial and dorsolateral prefrontal cortices, providing a context in which stimulus-independent behaviors may unfold in the absence of conscious monitoring and volitional control. Connectivity analyses reveal widespread improvisation-related correlations between medial prefrontal, cingulate motor, perisylvian cortices and amygdala, suggesting the emergence of a network linking motivation, language, affect and movement. Lyrical improvisation appears to be characterized by altered relationships between regions coupling intention and action, in which conventional executive control may be bypassed and motor control directed by cingulate motor mechanisms. These functional reorganizations may facilitate the initial improvisatory phase of creative behavior.

Hip-Hop music, in particular rap, has had a huge cultural impact in western society, especially among the young, since its appearance four decades ago. Freestyle rap, a popular form, requires an artist to freely improvise rhyming lyrics and novel rhythmic patterns, guided by the instrumental beat – a particularly challenging form of spontaneous artistic creativity.

It has been proposed that artistic creativity is itself a twofold process, in which an initial improvisatory phase, characterized by spontaneous generation of novel material, is followed by a period of focused re-evaluation and revision1. The neural correlates of the improvisatory phase are poorly understood1–8 Freestyle rap thus provides a unique opportunity to study this initial, improvisatory phase at the interface of music and language.

In an attempt to identify the neural correlates of spontaneous lyrical improvisation in this context we compared freestyle (improvised) to conventional (rehearsed) performance, using functional magnetic resonance imaging (fMRI). Utilizing spatial independent component analysis (sICA) methods recently developed in this laboratory to effectively remove imaging artifacts associated with connected speech or song, has made it possible to study this unique genre using fMRI for the first time. Importantly, in order to study spontaneous lyrical improvisation in its most natural form, our design evaluated the natural and ecologically valid process: freestyle artists producing freestyle rap, unencumbered by unrelated cognitive demands.

Spontaneous improvisation is a complex cognitive process that shares features with what has been characterized as a 'flow' state11. It has been suggested that the frontal lobe, may play a central role in the improvisatory process, although the nature of its contributions is unclear1. On this basis, in addition to its other characteristics, we expected the neural correlates of lyrical improvisation to include changes in prefrontal activity that might enable spontaneous creative activity through effects on systems that regulate attention, affect, language and motor control.

Our results support these predictions and provide a novel model for improvisation characterized by functional changes within a large-scale network that is anchored in the frontal lobe. This pattern – activation of medial and deactivation of dorsolateral cortices – may provide a context in which self-generated action is freed from the conventional constraints of supervisory attention and executive control, facilitating the generation of novel ideas11. Importantly, altered relationships within the prefrontal cortex appear to have widespread functional...
Results

Subjects were scanned while they performed two tasks, each of which used an identical 8-bar musical background track: 1) spontaneous, improvised freestyle rap (improvised) and 2) conventional performance of an overlearned, well-rehearsed set of lyrics (conventional). All figures and tables presented here are in Montreal neurological institute (MNI) space and are thresholded at a family-wise error rate less than 0.05 based on Monte Carlo simulations.

Language measures. Subjects’ scores on verbal fluency tests administered prior to the scanning sessions [29.3 ± 6.8 (mean ± s.d.) words generated in one minute on semantic; and 58.0 ± 11.1 in three minutes on phonological tests] were above the 80th percentile in each instance. This highlights the importance of superior linguistic skills in this genre, which requires rapid online formulation of meaningful, rhyming words and phrases within a prescribed tempo and rhythm.

GLM contrast of improvised vs. conventional conditions. To determine the neural correlates of spontaneous lyrical improvisation, we first compared improvised and conventional conditions directly using the general linear model (GLM) (Figure 1, a, b and Table 1). Improvised performance was characterized by significant increases in activity of the medial prefrontal cortex (MPFC), extending from the frontopolar cortex to the pre-supplementary motor area (pre-SMA) and decreases in the dorsolateral prefrontal cortex (DLPFC), extending from the orbital to superior regions. Medial prefrontal activations were lateralized to the left hemisphere; lateral prefrontal deactivations were lateralized to the right (Figure 1c).

The improvised condition was also associated with increased activity in perisylvian areas in the left hemisphere, including inferior frontal gyrus (LIFG), middle temporal (MTG) and superior temporal (STG) gyri, and intervening superior temporal sulcus (STS) and fusiform gyrus. Improvised performance was in addition associated with left lateralized activation of motor areas; these included the left lingual motor area (CMA), pre-SMA, dorsal premotor cortex (PMD), head and body of the caudate nucleus, and globus pallidus, and the right posterior cerebellum and vermis. Indices of articulatory movements did not differ between conditions: there were no significant differences in the number of syllables produced during improvised and conventional performance [994±103 (mean ± s.d.) and 1035±98 total syllables respectively].

Parametric modulation. We applied parametric modulation methods to determine how the innovative quality of performance might modulate these activity patterns. Using blinded ratings of performance quality (Table 2), we found significant associations between these measures and activity in the posterior and middle MTG and STS, the left MPFC, specifically lateral Brodmann area (BA) 9, a region near superior frontal sulcus, and the posterior cingulate cortex (PCC) (Figure 2).

Functional connectivity. Using a seed selected from the left lateral MPFC (guided by the parametric modulation results outlined above), we detected stronger negative correlations between activity in the MPFC and the ventral DLPFC (Figure 3a, indicating that the dissociated, reciprocal changes noted in these prefrontal areas in the above GLM contrasts are not independent; changes in one are tightly coupled to changes in the other). Similarly, activity in the MPFC was anticorrelated with activity in the intraparietal sulcus (IPS).

On the other hand, we detected stronger positive correlations between activity in the MPFC and the anterior perisylvian (LIFG) and cortical motor areas including cingulate motor area and adjacent anterior cingulate cortex (ACC), the pre-SMA and the dorsal lateral consequences, affecting motivation, emotion, language as well as motor control, and may generalize to other forms of spontaneous creative behavior.
we found that the left AMG was positively connected to an extended
network (Figure 3c), that included the right IFG and inferior parietal
lobules (IPL) and anterior insula in both left and right hemispheres.

Changes in activation patterns over time. To explore the possible
evolution of the creative process over time, we compared the con-
trast between improvised and conventional conditions at the begin-
ning and end (first and last measures) of each eight bar segment
(Figure 4). Activity in the left prefrontal, premotor, anterior

Table 2 | Guidelines for evaluating innovation in performance

| Factors considered | 
|-------------------|
| Creative use of Language | Did the participant generate a narrative? Did the participant vary the types of content? Did the participant avoid crutch phrases? (“you know”) Did the participant incorporate humor? Did the participant incorporate “uncommon” words? Did the participant expand upon topics that were introduced? Did the participant employ multi-syllabic rhyme schemes? Was the participant able to maintain a coherent rhyme scheme over longer periods of time (greater than two bars)? Did the participant vary rhythmic patterns? Were the varied patterns connected to rhyme schemes? Was the participant able to rap at a rapid rate? Was the participant able to maintain a complex rhyme over longer period of time? Was the participant able to use rhythm that resulted in innovative “phrasing” (e.g. extending rhyme schemes past their natural beginning and end points)?
| Creative use of Rhythm |
perisylvian language areas and amygdala identified in the initial GLM contrasts, was significantly higher at onset. In contrast, activations were greater in the right hemisphere by the final measure. The latter were found in regions that had been deactivated in the initial GLM contrasts, including the frontal eye fields and contiguous portions of the DLPFC, the dorsal premotor area, IPS, IPL and precuneus.

Discussion
In this study, we used fMRI to investigate the neural correlates of spontaneous lyrical improvisation by comparing spontaneous freestyle rap to conventional rehearsed performance. Our results reveal characteristic patterns of activity associated with this novel form of lyrical improvisation, and may also provide more general insights into the creative process itself. It has been suggested that the creative behaviors could occur in two stages: an improvisatory phase characteristic of activity associated with this novel form of spontaneous lyrical improvisation and may also provide more general insights into the creative process itself. It has been suggested that the creative behaviors could occur in two stages: an improvisatory phase characterized by generation of novel material and a phase in which this material is re-evaluated and revised. The present study may provide clues to the mechanisms that underlie the initial, improvisatory phase. Our results suggest a model in which an elementary reorganization of brain activity facilitates improvisation and may generalize to other forms of spontaneous creative behavior.

The most striking feature of lyrical improvisation detected by direct comparison of freestyle and conventional performance, in large part consistent with the previous study of melodic improvisation, was a dissociated pattern of activity within the prefrontal cortex: increases in activity throughout the MPFC, extending from the frontal pole to the border of the pre-SMA, and simultaneous decreases in the DLPFC, from its orbital to superior regions. The implications of this dissociation are discussed below, in the context of subsequent analyses.

A second salient feature of improvisation revealed by the GLM contrasts was a marked lateralization of task-related changes in the BOLD signal. For example, the medial prefrontal activations just noted were stronger in the left hemisphere, while dorsolateral prefrontal deactivations were stronger on the right. Similarly, additional task-related activations in language and motor areas were strongly lateralized to the left hemisphere, while additional deactivations in superior frontal and parietal areas were lateralized to the right.

Activation of left hemisphere language areas (in inferior frontal and posterior middle and superior temporal gyri) was predicted and is perhaps unsurprising given the nature of the genre. However it should be noted that activation here indicates enhanced activity, over and above levels observed during conventional performance, and so is not related to language processing per se. Instead activation of language-related cortices likely reflects the unique demands of freestyle improvisation, which requires rapid online selection of novel words and phrases that rhyme.

Increased activity in other left hemisphere regions associated with motor control (including medial and lateral premotor cortices, cingulate motor area and basal ganglia) does not appear to be related to increases in movement per se: there were no significant differences in quantitative indices of motor activity, including the number of syllables produced, during improvised and conventional conditions, and no condition-dependent differences in activity of the primary motor cortex were observed. Activity in these regions may instead reflect spontaneous phonetic encoding and articulation of rapidly selected words during improvisation. Enhanced activity in the caudate may also support rapid online sequencing of ongoing behaviors in this condition. Freestyle improvisation also requires that the articulation of words and phrases be spontaneously incorporated into established rhythmic patterns; this process might place additional demand on these regions. Additionally, both the cerebellar hemisphere and vermis, selectively activated during improvised performance, have been associated with maintenance of rhythmic patterns in working memory. The brain regions activated in association with rhyming and rhythmic variations may provide clues to mechanisms underlying the effects of musical intervention in clinical populations.
The widespread changes identified by the foregoing analysis are suggestive but incomplete. The questions that follow – how are these concurrent activations and deactivations related to one another; are they integrated in a meaningful way? – were addressed using connectivity analyses.

The connectivity results revealed strong positive correlations between activity in a primary seed region in the MPFC (located within the large cluster identified in the GLM contrast, selection was guided by the results of parametric modulation analyses) and inferior frontal and cortical premotor areas. To explore the potential extensions of this network, we tracked the extended connections of the inferior frontal and premotor regions themselves. Using each as a seed in subsequent analyses, we found that these regions were themselves positively correlated during right hemisphere regions (including the inferior and middle frontal gyri, the posterior parietal cortex and other posterior paraparamedian areas).

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conscious attention and effect motor control through alternate cingulate pathways— is one feature of a larger network, linking intention, affect, language and action, that may underlie and facilitate the initial, improvisatory phase of creative behaviors. We speculate that the neural mechanisms illustrated here could be generalized to explain the cognitive processes of other spontaneous artistic forms, which can be tested in future studies across disciplines.

**Methods**

**Subjects.** Twelve male freestyle artists (mean age, 30.3 yr; range, 23–36 yr) were studied. Participants had at least 5 years of professional experience, defined as performing in front of an audience, or recording projects for public consumption, and receiving payment for this work. The range of professional experience across participants was 5 to 18 years, 9.8 ± 4.3 (mean ± s.d.). All participants were right-handed native speakers of American English. Written informed consent was obtained from all participants under a protocol approved by the Institutional Review Board (NIH 92-DC-0178).

**Experimental design.** The set of lyrics used in the conventional condition was selected by two co-authors. These lyrics were easy to memorize, and participants had not been exposed to them before the experiments. A recording of material, which was performed on the background instrumental track used in the experiments, was sent to the participants to memorize one week before the experiments. Prior to the imaging experiments, participants were asked to perform phonemic (generating words beginning with a specific letter) and categorical (animal naming) verbal fluency tests. Participants then went through a training session, in order to make sure they performed all experimental conditions correctly before scanning. The participants were asked not to move their heads or other parts of their body during the scan. In order to constrain head motion, foam pads were used for support in the head coil. In both pilot and actual experiments, debriefing indicated that participants’ performance was not affected by the motion restraints.

In the conventional condition, the participants were asked to rap the memorized lyrics on the 8-bar instrumental track. In the improvised condition, lyrics were improvised spontaneously, on the same instrumental track. An 8-bar instrumental track at 85 beats per minute was created by a co-author and repeatedly used as the background music for the whole experiment. A two-beat auditory prompt were placed at the beginning of the eighth bar to indicate the end of the 8 bars. Participants performed two sessions during the scan, of which each included 6 blocks (22.53s per block) of improvised and conventional conditions per session in an alternating box-car design.

**MRI scanning.** T2*-weighted BOLD images were acquired on a General Electric (GE) Signa HDx 3.0 Tesla scanner (GE Healthcare, Waukesha, WI, USA) with an 8-channel High Resolution Brain Coil. Anatomical images were acquired using a magnetization-prepared rapid gradient-echo (MPRAGE) sequence. A single-shot gradient-echo EPI sequence was used for functional imaging; the acceleration factor of ASSET (Array Spatial Sensitivity Encoding Technique) = 2, TR (repetition time) = 2000 ms, TE (echo time) = 30 ms, flip-angle = 90°, 64×64 matrix, FOV (field of view) = 227 mm, 4 dummy scans. 40 interleaved sagittal slices with a thickness of 4 mm were used to cover whole brain. Because the majority of head motion during the 8 bars of the instrumental track is caused by respiration, the motion was minimized by this setup and the advantage of in-plane image registration23 was maximized. The audio of participants’ performances were recorded by a FOMRI® II noise canceling optical microphone (Optacoustics, Or Yehuda, Israel).

**Data analysis.** Time‐locked, denoised auditory recordings were collected during each block from all participants. Syllables produced in each block were measured for both conditions by detecting syllable nuclei based on salient voiced peaks. After the experiment, auditory recordings acquired during improvised blocks were evaluated blindly by two experienced musicians who assessed the creative use of language and rhythm, assigning a consensus score using 10-point scale (Table 2), for use in the parametric modulation analyses.

The structural image of each subject was first segmented and normalized into MNI space using the tissue probability maps (TPMs) in SPM8 (Wellcome Department of Imaging Neuroscience, London, UK, http://www.fil.ion.ucl.ac.uk/spm/). In‐plane registration, slice‐time correction and volumetric rigid‐body registration were sequentially applied to the functional datasets. Such traditional motion correction algorithms are effective in correcting misalignments caused by bulk head movements, but not motion‐related susceptibility artifacts associated with overt speech production. To minimize the latter, spatial independent component analysis (sICA) was applied24. In sICA, each BOLD image was treated as a mixture of multiple statistically independent signal and noise sources. The number of components in each dataset was estimated by minimum description length (MDL) criterion25. The systematic classification of artificial and neuronal ICA components was based on their degree of spatial clustering, location of major positively weighted clusters and neighborhood connectedness between positively and negatively weighted clusters. The noise components identified by a human‐expert using these criteria and their variances were subsequently removed. Inter‐rater reliability was assessed among five raters (including the current rater) by Fleiss’ kappa test in an independent dataset consisting

(figure 2) including the posterior and middle MTG and STS, and the MPFC. This suggests that regions that may correspond to the location of the medial leson (in which words and their semantic features are stored26, likely consistent with subjects’ superior performance on verbal fluency tests), and regions that play a role in motivation, drive and self‐organized behavior, may play a prominent role in the innovative use of language and rhythm. Interestingly, parametric modulation also highlighted an area not implicated in the GLM contrasts, the left posterior cingulate cortex (PCC), which has been shown to play a role, along with the MPFC, in self‐motivated or self‐referential behaviors27.

We also observed interesting, systematic differences in the patterns of activity in the first and last measures of the eight bar segments that constitute the basic unit of this musical form. Surprisingly we found that activity in the set of left prefrontal, premotor, anterior perisylvian language areas and amygdala reported above, was relatively higher at onset, but that activations in general appeared to shift to the right hemisphere by the final measure. This indicates first of all that the network related to motivation, emotion and language identified above may be more strongly engaged in initiating the improvisation.

What the relative increases in activity in the right hemisphere at the end of each segment indicate is however not clear. It is interesting that many of these increases were found in regions that were deactivated in the principal improvised‐conventional contrast reported above. The time dependent increases in activity of frontal eye fields and IPS might reflect a re‐emergence of top‐down attentional processing at the end of each improvisational sequence, and increasing activity in the dorsolateral prefrontal cortices might reflect an increase in executive functions mediated by these regions. It is possible that rule based behaviors (e.g. attention to metric structure, selection of final lyrical elements) may be more important, and may re‐engage these regulatory mechanisms, at the end of each 8 bar segment. It is clear nevertheless that the notion that simple attenuation of attention and executive control supports improvisation may be an oversimplification and that these processes seem to vary in a more complex way over time. The mechanisms underlying these interactions between musical improvisation and temporal structure clearly warrants further investigation.

As noted above, creativity may actually be a biphasic process involving initial free generation and subsequent revision of novel material2. Here we have examined only the first, spontaneous or improvisational phase. As we report, improvisation, contrasted with conventional performance, was in general associated with relative decreases in activity in supervisory attentional and executive systems. Were our subjects to actively reevaluate and revise the lyrics they had improvised, we might predict activation of these systems in support of evaluative processes that more likely require attention to and conscious, goal‐directed revision of the original material. Indeed, a recent imaging study of graphic design did show activation of executive systems including the DLPFC specifically during subjects’ evaluation of their prior creative outputs1.

Compared to previous studies of musical improvisation by Ullen and his colleagues28, Berkowitz & Ansari29 and Brown et al.7, our results differ in one fundamental way. While elegantly designed in order to enforce tight experimental control, these studies used conditions that were less spontaneous and may have imposed additional attentional and mnemonic demands (e.g improvised material had to be memorized as it was generated and reproduced during a subsequent scanning run); this might in part account for the activation of the DLPFC reported in these studies. In contrast, we observed significant deactivation of the DLPFC (along with activation of the MPFC) and it is possible that this pattern may emerge when spontaneous improvisation takes place without the superimposition of secondary cognitive tasks.

In summary, the functional reorganization we observe – in which the medial prefrontal cortices may guide behavior in the absence of
of 18 subjects. The Fleiss' kappa value of 0.0869 indicated almost perfect agreement among the raters. Afterward, the denoised data were normalized into MNI space at a voxel size of 3 x 3 x 3 mm by applying the transforms derived from the structural image normalization, and smoothed to a target full-width-half-max (FWHM) of 10 mm.

At the subject level, the GLM was implemented using SPM8. Separate regressors were constructed by convolving the box-car function of each condition with the canonical hemodynamic response. In addition to task regressors, a nuisance covariate of the whole-brain mean signal was used to account for the global BOLD signal fluctuations induced by changes in PCO2 during continuous overt speech production40–42. To the whole-brain mean signal was used to account for the global BOLD signal fluctuations, a band-pass filter of 0.045–0.1 Hz was applied on the residual in MATLab (version R2010A, The MathWorks Inc., Natick, Massachusetts) to ensure that estimated connectivity between regions was not affected by high-frequency physiological noise or low-frequency fluctuations caused by scanner signal drifts and stimulus on-off manipulations. The data for each condition were shifted by three volumes to account for the delay (approximately 6 seconds) of the hemodynamic response, and then concatenated. For each condition, a correlation map was generated in AFNI14 by calculating the Pearson’s correlation coefficient between the eigenvector of time series of all voxels within a 5-mm sphere centered at the seed’s coordinate, and each voxel’s time series in the brain. The correlation coefficients were then Fisher's r-to-z transformed and input in a random-effect ANOVA model to compare the connectivity changes between the two task conditions at a group level in SPM8. For both GLM and connectivity analyses, Monte Carlo simulations were used to determine cluster size threshold for family-wise error correction.

To select the seed of MFPC for the functional connectivity analysis, we took into account both the GLM results (improvised vs. conventional) and parameter modulation of prefrontal cortex of monkeys. Since activation derived from the improvised vs. conventional contrast was large, extending from the frontal pole to the pre-SMA, we divided this cluster into 6 sub-regions, using the division from the SCIENTIFIC REPORTS.

To identify the effect of innovative performance, a separate GLM model was built with the addition of a regressor of performance scores for all improvised blocks. To estimate the evolution of improvised performance over time, in addition to the main regressors, additional regressors were added indicating 1st and 8th bar for both conventional and improvised conditions. In each case, a group-level voxel-wise random-effects ANOVA model was used to draw statistical inferences at the population level.

A seed based functional connectivity analysis was performed on the residual time-series of each voxel. For each participant's GLM, a band-pass filter of 0.045–0.1 Hz was applied on the residual in MATLab (version R2010A, The MathWorks Inc., Natick, Massachusetts) to ensure that estimated connectivity between regions was not affected by high-frequency physiological noise or low-frequency fluctuations caused by scanner signal drifts and stimulus on-off manipulations. The data for each condition were shifted by three volumes to account for the delay (approximately 6 seconds) of the hemodynamic response, and then concatenated. For each condition, a correlation map was generated in AFNI14 by calculating the Pearson’s correlation coefficient between the eigenvector of time series of all voxels within a 5-mm sphere centered at the seed’s coordinate, and each voxel’s time series in the brain. The correlation coefficients were then Fisher’s r-to-z transformed and input in a random-effect ANOVA model to compare the connectivity changes between the two task conditions at a group level in SPM8. For both GLM and connectivity analyses, Monte Carlo simulations were used to determine cluster size threshold for family-wise error correction.

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Author contributions
S.L., A.R.B., H.M.C., Y.X., D.A.R. and M.W.E. designed the study. S.L. and A.R.B. interpreted the data and wrote the paper. S.L., H.M.C. and M.G.E. collected fMRI and behavioural data. K.E.S., D.A.R. and M.W.E. conducted behavioural data analysis. S.L. conducted neuroimaging analyses with the help of Y.X. and H.M.C. All authors commented on the manuscript.

Additional information
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