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Drumming To Communicate Emotion: Dual-Brain Imaging Informs An Intervention In A Carceral Setting

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Drumming to Communicate Emotion: Dual-Brain Imaging Informs an Intervention in a Carceral Setting

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DRUMMING TO COMMUNICATE EMOTION: DUAL-BRAIN IMAGING INFORMS AN INTERVENTION IN A CARCERAL SETTING. Rahil Rojiani (Sponsored by Joy Hirsch and David Sells). Department of Psychiatry, Yale University, School of Medicine, New Haven, CT.

ABSTRACT

Drumming is an ancient nonverbal communication modality for expression of emotion. However, there has been limited exploration of its possible applications in clinical settings. Further, the underlying neural systems engaged during live communication with drumming have not been identified. We investigated the neural response to live, natural communication of emotion via drumming using a novel dual-brain neuroimaging paradigm to discover its unique neurophysiological mechanisms related to drum behavior and cross-brain coherence, and as compared to talking. We then investigated the application of a drumming intervention in an incarcerated, halfway house population to characterize intervention feasibility, elucidate the phenomenology of social and emotional effects of group drumming, and identify its possible benefits for treatment engagement and community reintegration. For neural response investigation, hemodynamic signals were acquired using whole-head functional near infrared spectroscopy. Dyads of 36 subjects participated in two conditions, drumming and talking, alternating between “sending” (drumming or talking to partner) and “receiving” (listening to partner) in response to emotionally salient images from the International Affective Picture System. Results indicated that increased frequency and amplitude of drum strikes was behaviorally correlated with higher arousal and lower valence measures, and neurally correlated with temporoparietal junction (TPJ) activation in the listener. Contrast comparisons of drumming greater than talking also revealed neural activity in right TPJ. For the interventional investigation, a group drumming program was implemented once a week for eight weeks for incarcerated participants in a halfway house. Twenty-eight participants were randomized to either the drum group or treatment as usual. Interviews and a focus group were conducted to assess the experienced benefits of the group drumming intervention, and halfway house retention rates were compared across groups. Retention rate was significantly higher in the drum group than in the treatment as usual group. Qualitative analysis elicited three themes: group drumming 1) functions therapeutically as a method of coping with difficulty, 2) offers opportunity for connection through building relationship and experiencing communion in a setting where isolation is the norm, and 3) provides an environment for personal growth, particularly toward re-humanization and self-empowerment. Neural findings suggest that emotional content communicated by drumming engages right TPJ mechanisms in an emotionally and behaviorally sensitive fashion; interventional findings suggest significant therapeutic potential in social and emotional domains that can have quantifiable impact on recovery process. Together, findings suggest that drumming may provide access to neural mechanisms with known sensitivity to social and emotional conditions that facilitates therapeutic aims. Informed by this research, drumming may provide novel, effective clinical approaches for treating social-emotional psychopathology.

ACKNOWLEDGEMENTS

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INTRODUCTION

Drumming is an ancient nonverbal form of communication that has been used across the world throughout history. While its historical and current usage suggest important social and emotional functions, it has been understudied in these contexts. We aim to investigate these socio-emotional functions and effects through both neuroimaging and qualitative analysis. This study utilized a simultaneous, dual-brain neuroimaging paradigm to study bidirectional communication of emotion via drumming, including sending and receiving emotional content. Further, this study implemented a group drumming intervention for an incarcerated community and explored participants' subjective experiences to provide context to neural findings and generate hypotheses for future research and clinical application.

Historical and Cultural Use of Drumming. Drumming has been a part of human cultures worldwide for millennia, with some of the earliest discovered drums dating back to 5500-2350 BCE (L. Liu, 2005). They have typically played a communicative role in social settings, which may point to their evolutionary origin (Randall, 2001; Remedios, Logothetis, & Kayser, 2009). For example, slit drums and slit gongs – used from the Amazon to Nigeria to Indonesia – often use particular tonal patterns to convey messages over distance (Stern, 1957). Similarly, the renowned "talking drums" of West Africa convey information with stereotyped stock phrases that mimic the sounds and patterns of speech (Arhine, 2009; Carrington, 1971; Oluga & Babalola, 2012; Stern, 1957). These drums have been used to communicate messages over thousands of kilometers by relaying from village to village (Gleick, 2011). However, these drums are also used in other communal settings, including dancing, rituals, story-telling, and other ceremonies (Carrington, 1971; Ong, 1977), suggesting that they hold not only semantic information but also emotional information.

Drums are typically used in social or ceremonial settings, without holding semantic information and without intention to mimic speech. Such drumming serves various functions of emotional communication, such as to instill motivation or fear (e.g. during war), synchronize group activity (e.g. agricultural work or marching), or build social cohesion (recreational and ceremonial drum circles). For example, Wolf (2000) explores how drums are used amongst South Asian Shi'i Muslims in the mourning process that commemorates the killing of a political and spiritual leader at the Battle of Karbala in 680 CE. He points to how various qualities of drumming may facilitate the listener's emotional relationship with the event (e.g. slow tempo for sadness, loud drum strikes for the intensity of grief).

Studying Bidirectional Emotion Communication via Drumming. The use of drums in situations where verbal communication is also used suggests that drumming provides added value to verbal communication, possibly deepening the emotional experience. This potentially unique or supplemental contribution to emotion communication merits investigation and may have clinical application. Unfortunately, research on the communication of emotion has focused primarily on the neural mechanisms of communicating via speech, which this study seeks to remedy. Further, the communication of emotion is a bidirectional process, which includes both sensitivity to the emotional cues of others as well as the expression of internal emotional states to others. Generally, emotion research has focused on the unidirectional process of perception or induction (i.e. the brain's reactivity to emotional stimuli), in large part due to the limitation of conventional neuroimaging modalities to single subjects. In this study, we first aim to understand the putative neural mechanisms that underlie bidirectional communication of emotion via drums, using an imaging modality that can capture bidirectionality in an ecologically valid way. These results then inspire and inform a clinical application in a carceral setting, in which quantitative and qualitative results may further characterize this added or unique contribution of drumming in social-emotional contexts for possible therapeutic benefit.

INTRODUCTION

Functional Near Infrared Spectroscopy (fNIRS). Functional near infrared spectroscopy (fNIRS) uses signals based on hemodynamic responses, similar to fMRI, and with distinct features that are beneficial for the study of live, natural, bidirectional communication. For example, the signal detectors are head-mounted (i.e. non-invasive caps), participants can be seated directly across from each other while being simultaneously recorded, the system is virtually silent, and data acquisition is tolerant of limited head motion (Eggebrecht et al., 2014). These features facilitate a more ecologically valid neuroscience of dual communicating brains (Fig 1).

Figure 1. Experimental Setup. fNIRS Setup for two partners interacting via drumming.

The fNIRS hemodynamic signals are based on differential absorption of light at wavelengths sensitive to concentrations of oxygenated and deoxygenated hemoglobin in the blood. As with functional MRI, observed variation in blood oxygenation serves as a proxy for neural activity (Ferrari & Quaresima, 2012; Gagnon et al., 2014; Kato, 2004; Scholkmann et al., 2013). Although it is well documented that blood oxygen level dependent (BOLD) signals acquired by functional magnetic resonance imaging (fMRI) and hemodynamic signals acquired by fNIRS are highly correlated (Sato et al., 2013; Strangman et al., 2002), the acquired signals are not identical. The fNIRS system acquires both oxygenated hemoglobin (oxyHb) and deoxygenated hemoglobin (deoxyHb). The deoxyHb signal most closely resembles the fMRI signal (Sato et al., 2013; Zhang, Noah, & Hirsch, 2016) and is thus reported here. The fNIRS signals originate from larger volumes than fMRI signals, limiting spatial resolution (Eggebrecht et al., 2012). However, the fNIRS signal is acquired at a higher temporal resolution than the fMRI signal (20-30 ms versus 1.0-1.5 s), which benefits dynamic studies of functional connectivity (Xu Cui et al., 2011). Due to the mechanics of emitting infrared light, the sensitivity of fNIRS is limited to cortical structures within 2-3 cm from the skull surface. Although fNIRS is well established (particularly in child research where fMRI approaches remain difficult or contraindicated), recent adaptations of fNIRS for hyperscanning enable significant advances in the neuroimaging of neural events that underlie interactive and social functions in adults (Cheng, Li, & Hu, 2015; Dommer et al., 2012; Funane et al., 2011; Hirsch et al., 2017; Holper, Scholkmann, & Wolf, 2012; Jing Jiang et al., 2015; Osaka et al., 2015; Piva et al., 2017; Vanutelli, Crivelli, & Balconi, 2015).

Study Overview. We investigated the neural response to the communication of emotional content of visual stimuli via drumming in a face-to-face paradigm, eliciting the contribution of drumming to auditory emotion communication. We chose drumming as the communication modality given its accessibility to a first-time user, thus enhancing the potential for clinical application. In our experimental paradigm, pairs of subjects (dyads) were presented with images from the International Affective Picture System (Lang, Bradley, & Cuthbert, 2008), which served as the topic for communication via either drumming or talking. We identified the relationship between drumming behavior and arousal or valence of the IAPS images. We then evaluated the neural sensitivity to drum behavior in both drummer and listener in order to characterize the communication of emotion. We followed with a comparison of the neural correlates of drumming and talking to evaluate the possible unique neural contribution of drumming over talking as a communication modality. Finally, we compared cross-brain coherence during drumming between the standard “monologue” task and a more interactive “dialogue” task in order to evaluate the extent of interactive processes.

The IAPS images employ a two-dimensional emotion framework that distinguishes the emotional qualities of arousal and valence, as most classically represented in Russell’s circumplex model (1980). Arousal is a measure of the intensity or activating capacity of an emotion, ranging from low (calm) to high (excited); low arousal emotions may include sadness or contentedness, while high arousal emotions may include excitement or anger. Valence is a measure of the pleasure quality of the emotion, ranging from negative (unpleasant) to positive (pleasant); negative valence emotions may include sadness or anger, while positive valence emotions may include contentedness or excitement. Each of the IAPS images are indexed by valence and arousal ratings, allowing us to regress neural activity against these emotional qualities (Lang et al., 2008). Examples plotted by these valence and arousal ratings are shown in Fig 2.

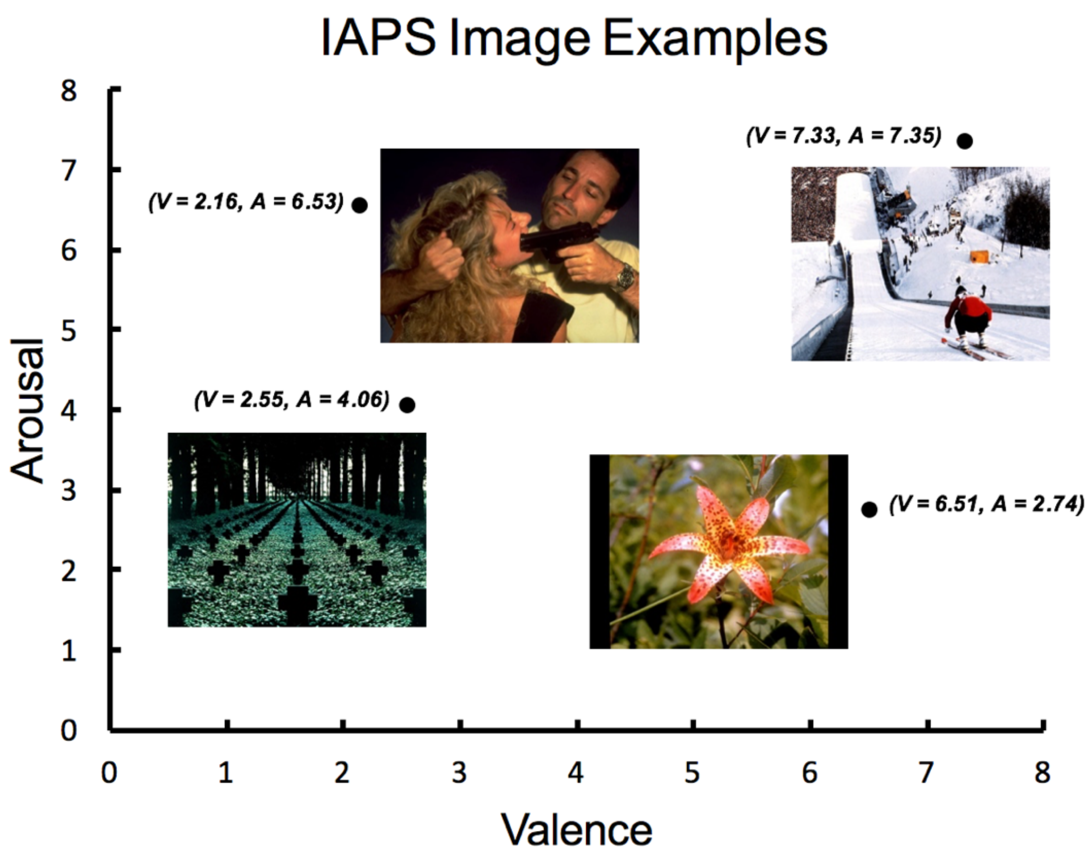


Figure 2. IAPS Image Examples. Examples of IAPS images with low/high arousal (*A*) and negative/positive valence (*V*). The figure illustrates the arousal/valence index system for emotional qualities of each image.

We are informed by extensive literature highlighting the importance of the temporoparietal junction for social and emotional processing (Carter & Huettel, 2013). This has been demonstrated in particular for emotional processing of music (Blood et al., 1999; Zatorre, 1988; Zatorre et al., 1992). Social drumming may elicit these right-lateralized social and emotional circuits without simultaneously requiring significant left-lateralized semantic processing otherwise required for talking, holding implications for their comparison.

Thus, the hypothesis for this investigation was three-fold. First, we hypothesized that strike-by-strike drum measures that communicate expressions of valence and arousal would elicit activity in brain systems associated with social and emotional functions, i.e., the right temporoparietal junction. Second, we hypothesized that drumming in response to emotional stimuli would elicit neural activity that was greater than talking in the right temporoparietal junction. Third, we hypothesized that cross-brain coherence for “dialogue” drumming would exceed cross-brain coherence for “monologue” drumming within the areas associated with drumming and communication, i.e., the right temporoparietal junction.

METHODS

Participants. Thirty-six (36) healthy adults (18 pairs of subjects; mean age 23.8 ± 3.2; 86% right handed (Oldfield, 1971)) participated in the study. Sample size is based on power analyses of similar prior two-person experiments showing that a power of 0.8 is achieved by an n of 31 (Hirsch et al., 2017). All participants provided written informed consent in accordance with guidelines approved by the Yale University Human Investigation Committee (HIC #1501015178) and were reimbursed for participation. Dyads were assigned in order of recruitment; participants were not stratified further by affiliation or dyad gender mix. All participant recruitment, dyad assignment, consenting, and survey administration were conducted by the author.

Participants rated their familiarity with their partner, their general musical expertise, and their drumming expertise (descriptive statistics in Table 1). To facilitate drumming as a method of communication for participants regardless of previous experience, a brief interactive video tutorial was shown to all participants to acquaint them with various ways of striking the drum using both hands.

Table 1. fNIRS Study Demographic Information

Category	Subcategory	Total / Avg
N		36
Age		23.8 ± 3.2
Gender		
	Male	17
	Female	19
	Other	0

Race		
	Asian/Pacific Islander	17
	Black / African American	2
	Latinx / Hispanic	0
	Middle East / N African	1
	Native / Indigenous	0
	White / European	10
	Biracial/Multiracial	7
	Other	2
Dyad Gender Mix		
	Male/Male	5
	Male/Female	8
	Female/Female	5
Handedness		
	Right	31
	Left	5
Music Expertise[A]		3.14 ± 1.22
Drum Expertise[A]		1.64 ± 0.93
Partner Familiarity[A]		1.53 ±1.23

[A]Based on Likert Scale responses ranging 1 to 5 for Musical Expertise (never played to plays professionally), Drumming Expertise (never played to plays professionally), and Partner Familiarity (never seen or spoken to best friends).

Experimental Paradigm. Dyads were positioned face to face across a table 140cm from each other (See Fig 1, showing the drumming condition; the talking condition was identical, but without the drum apparatus). Pseudo-randomized image stimuli presented on each trial were selected from a subset of the International Affective Picture System (IAPS) (Lang et al., 2008). These images were presented to both participants via a monitor on each side of the table that did not obstruct view of their partner. In each trial, one subject responded to the image stimulus by drumming or talking while the other listened.

In the drumming condition, participants were encouraged to respond to the image however they felt appropriate, including a direct response to the emotional content of the image, drumming as if they were acting within the image (e.g. with punches or strokes), or drumming as if creating the soundtrack to the image. In the talking condition, participants were encouraged to speak about what they see, their experience with the elements of the image, their opinion about the image or elements within it, or what came to mind in response to the image.

The images changed and roles alternated between “sending” (drumming or speaking) and “receiving” (listening to partner) every 15 seconds for 3 mins (Fig 3). For example, as illustrated in Fig 3 Event 1, after Subject 1 had spoken about the space shuttle liftoff for 15 seconds while Subject 2 listened, an image of flowers (Fig 3, Event 2) replaced the space shuttle image on both subjects’ screens, cuing Subject 2 to speak about this new image while Subject 1 listened. This 3-minute run of alternating “sending” and “receiving” is repeated for 4 epochs of each communication type (drumming and talking) for a total of 12 epochs. This was then repeated for a total of two runs of drumming and two runs of talking for each pair of subjects.

This paradigm was expanded for the drum coherence analysis. The above description was referred to as the monologue condition, and the dialogue condition was identical to the monologue one except that with the new epoch and role switch, the new “sender” first drummed a response to what the previous partner had drummed (in reference to the prior picture) before drumming about the new picture. Participants were instructed to change topics from “your partner’s drumming about the previous picture” to “your own drumming about the new picture” near the middle of the epoch. The exact time of the topic switch was not specified to assure that communication flowed as naturally as possible.

For each dyad, the following conditions were pseudo-randomized: order of experiment runs (i.e. dialogue runs first or drumming runs first), order of subjects responding within runs, order of subjects responding across runs. The order of presentation of the series of 96 images for each experiment was also randomized.

Development of the Experimental Paradigm was conducted by the author with assistance from faculty advisor and lab members.

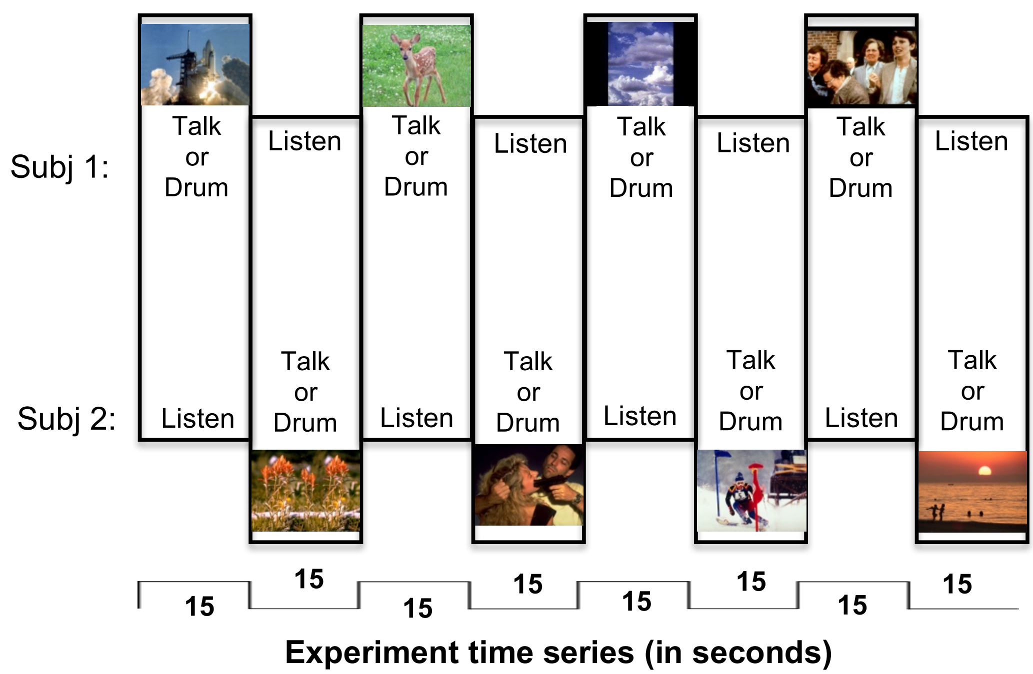


Figure 3. Experimental Paradigm. Each run is 3 min, 12 epochs (8 epochs shown here). Subjects alternate “sending” (speaking or drumming) and “receiving” when triggered by image change. Each image was selected from the IAPS library with established arousal and valence ratings.

Image Stimuli. The stimuli used for each experiment were a set of 96 images selected from the International Affective Picture System (IAPS) (Lang et al., 2008). These images have established ratings for arousal (low to high) and valence (negative to positive) on a 1-9 Likert scale. Examples are given in Fig 2, and a scatterplot depicting the valence and arousal distributions of our image subset is included in Figure S1 (Supplementary Material).

Behavioral Data

Quantified Drumming Response. The electronic drums utilized for this study use a Musical Instrument Digital Interface (MIDI) protocol to record quantity and force of drum strikes. For each run, we collected strike-by-strike information, including the average force of drum strikes, the total number of drum strikes, and the product of these two values (providing a combined objective quantification of drumming response). This quantified drumming response was then correlated with the established arousal and valence ratings for image stimuli, serving as a behavioral measure of responses to IAPS images. Strike-by-strike measures were taken as the "sending" variable. This analysis was conducted by the author.

fNIRS Data

Signal Acquisition and Processing. NIRS signal acquisition, optode localization, signal processing including global mean removal used here are similar to standard methods described previously for the deoxyHb signal (Dravida et al., 2017; Hirsch et al., 2018; Hirsch et al., 2017; Noah et al., 2017; Noah et al., 2015; Zhang et al., 2017; Zhang et al., 2016). Hemodynamic signals were acquired using a 64-fiber (84-channel) continuous-wave fNIRS system (Shimadzu LABNIRS, Kyoto, Japan). The cap and optode layout of the system provided extended head coverage for both participants achieved by distribution of 42 3cm channels over both hemispheres of the scalp (Fig 4). Anatomical locations of optodes in relation to standard head landmarks were determined for each participant using a Patriot 3D Digitizer (Polhemus, Colchester, VT) (Eggebrecht et al., 2012; Ferradal et al., 2014; Okamoto & Dan, 2005; Singh et al., 2005). The Montreal Neurological Institute (MNI) coordinates (Mazziotta et al., 2001) for each channel were obtained using NIRS-SPM software (Ye et al., 2009), and the corresponding anatomical locations of each channel were determined by the provided atlas (Rorden & Brett, 2000). Table S1 (Supplementary Material) lists the median MNI coordinates and anatomical regions with probability estimates for each of the channels shown in Fig 4. Signal acquisition and digitizing were conducted collaboratively amongst the author and other lab members using pre-established lab techniques.

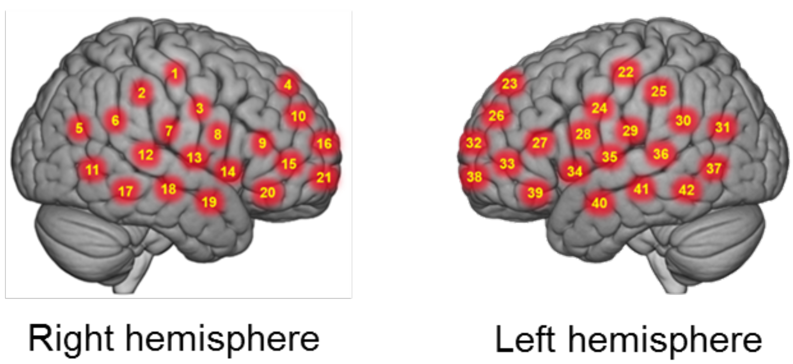


Figure 4. Channel Locations. Right and left hemispheres of a single rendered brain illustrate average locations (red circles) for channel centroids. See Table S1 (Supplementary Material) for average MNI coordinates and anatomical locations.

We applied pre-coloring in our experiment through high-pass filtering. Pre-whitening was not applied to our data. This decision was guided by a previous report showing a detrimental effect on neural responses during a finger-thumb-tapping task (Ye et al., 2009). Baseline drift was modeled based on the time series and removed using wavelet detrending provided in NIRS-SPM. Global components resulting from systemic effects such as blood pressure (Tachtsidis & Scholkmann, 2016) were removed using a principal component analysis (PCA) spatial filter (Zhang et al., 2016) prior to general linear model (GLM) analysis. Comparisons between conditions were based on the GLM (Penny et al., 2011). Event epochs were convolved with a standard hemodynamic response function modeled to the contrast between “sending” (drumming or talking) and “receiving” (listening), providing individual beta values of the difference for each participant across conditions. Group results were rendered on a standardized MNI brain template. This processing and data analysis was conducted primarily by a lab member with assistance and direction from the author.

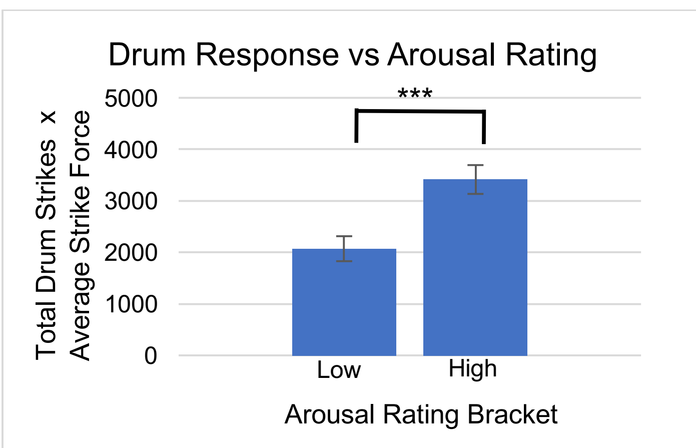
Brain-to-Brain Synchrony. Cross-brain coupling is defined as correlations between the hemodynamic signals of two brains (Xu Cui et al., 2011; Hirsch et al., 2018; Hirsch et al., 2017; Jing Jiang et al., 2015; Piva et al., 2017). The coherence of wavelet components from averaged regional signals across two brains (Torrence & Compo, 1998) provided an indication of cross-brain synchrony during the sending and listening exchanges and compared for the two drumming conditions, monologue and dialogue. We investigate this synchrony across the TPJs of each partner, using the four closest channels to the centroid of the (right lateralized) TPJ mask as determined by a search on Neurosynth for temporoparietal junction. This analysis was also applied to scrambled (random pairs) of dyads to control for possible effects of common processes. These analyses were conducted by a lab member with direction from the author.

RESULTS

Behavioral Results

Drumming Related to Arousal and Valence. Pearson product-moment correlations were determined between the established arousal ratings for each image and the quantified behavioral measure of drumming response. We observed a positive correlation (*r* = 0.37), indicating that drumming responses increased with more arousing image stimuli (Fig 5A). Pearson product-moment correlations were also determined between the established valence ratings for each image and the quantified drumming response. We observed a negative correlation (*r* = -0.22), indicating that drumming responses decreased with more positive-mood image stimuli (Fig 5B).

A)



B)

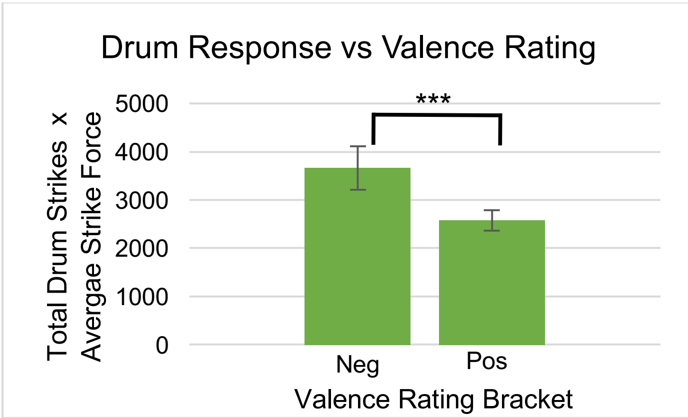


Figure 5. A: Drum Response vs Arousal Rating. A positive correlation (*r* = 0.37) was observed between the quantified drumming response (number of drum strikes multiplied by average drum strike force) and the arousal ratings of IAPS image stimuli. The bars represent two brackets equally dividing our range of IAPS image stimuli arousal ratings (lowest arousal 2.63 to highest arousal 7.35), $p<0.001$. **B: Drum Response vs Valence Rating:** A negative correlation (*r* = -0.22) was observed between the quantified drumming response (number of drum strikes multiplied by average drum strike force) and the valence ratings of IAPS image stimuli. The bars represent two brackets equally dividing our range of IAPS image stimuli valence ratings (lowest valence 2.16 to highest valence 8.34), $p<0.001$.

fNIRS Results

Neural Responses to Drumming (Sending) and Listening (Receiving). In this contrast comparison of drumming ("sending") and listening ("receiving"), we convolved the strike-by-strike drum intensities with the hemodynamic response function of the block (Fig 6). Contrast comparisons of listening > drumming (blue) show activity in the right hemisphere that correlates with greater amplitude and frequency of drum response, including Supramarginal Gyrus (BA40), Superior Temporal Gyrus (BA22), Angular Gyrus (BA39), Superior Temporal Gyrus (BA22), and Middle Temporal Gyrus (BA21). These regions are included in the temporoparietal junction (TPJ). On the other hand, comparisons of drumming > listening (red) show activity in two clusters, one in each hemisphere, that correlate with greater amplitude and frequency of drum response. The cluster on the right hemisphere has a spatial distribution including pre-motor and supplementary motor (BA6) and primary somatosensory cortex (BA1,2,3). The cluster on the left has a spatial distribution including pre-motor and supplementary motor cortex (BA6). Together, they are labeled Sensory Motor Cortex (SMC).

Neural Responses to Drumming and Listening

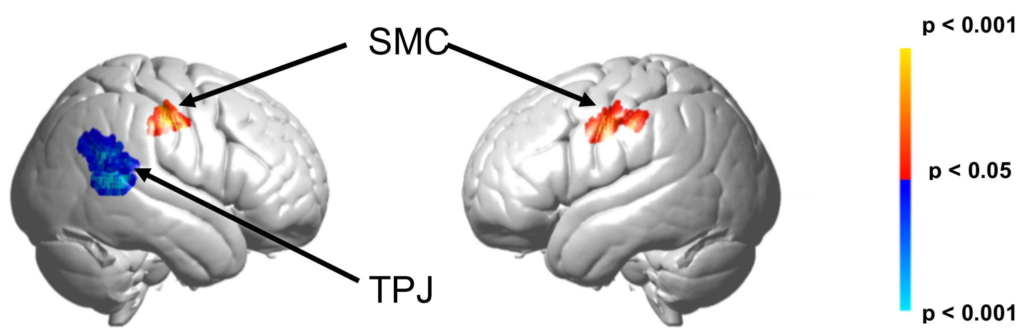


Figure 6. Neural Responses to Drumming and Listening. Convolving strike by strike drumming intensities with the hemodynamic response function for the drumming ("sending") block, the listening condition shows greater activity than the drumming condition in two loci (blue), both in the right hemisphere. The first peak voxel was located at 64, -52, 24 ($T=-3.49$, $p<0.00078$, $p<0.05$ FDR corrected), and it included supramarginal gyrus (BA40) 49%, superior temporal gyrus (BA22) 35%, and angular gyrus (BA39) 16%. The second peak voxel was located at 64, -46, 6 ($T=-3.84$, $p<0.00031$, $p<0.05$ FDR corrected), and it included superior temporal gyrus (BA22) 56%, and middle temporal gyrus (BA21), 40%. In contrast, the drumming ("sending") condition shows greater activity than the listening ("receiving") condition in two loci (red), one in each hemisphere. The right hemisphere peak voxel was located at 60, -16, 42 ($T=3.58$, $p<0.00061$, $p<0.05$ FDR corrected), and it included pre-motor and supplementary motor cortex (BA6) 43% and primary somatosensory cortex (BA 1, 2, 3) 18%, 12%, 17%. The left hemisphere peak voxel was located at -50, -6, 36 ($T=3.11$, $p<0.00211$), and it included pre-motor and supplementary motor cortex (BA6) 100%.

Comparison of Drumming and Talking. Contrast comparisons of drumming > talking show both left and right hemisphere activity (Fig 7). The spatial distribution of the right hemisphere cluster included the supramarginal gyrus (BA 40), the superior temporal gyrus (BA 22), and the primary somatosensory cortex (BA 2). The spatial distribution of the left hemisphere cluster included the primary somatosensory cortex (BA 2) and the supramarginal gyrus (BA 40).

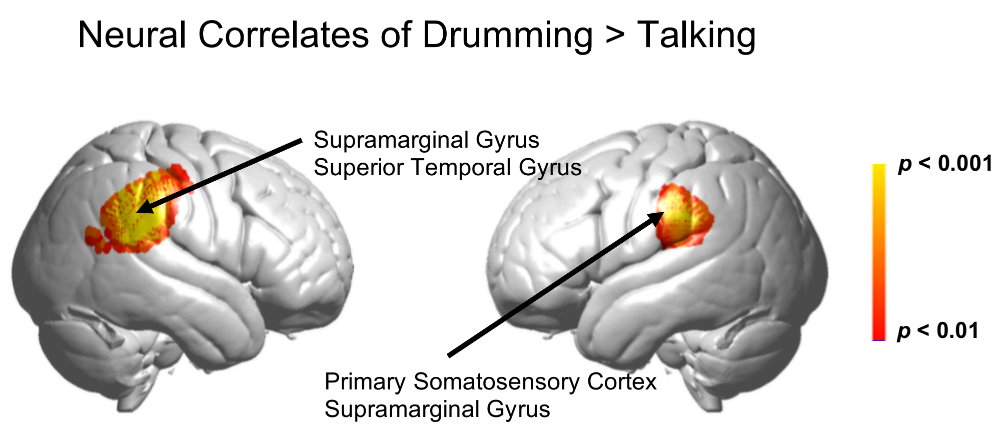


Figure 7. Neural Correlates of Drumming > Talking. Collapsing across qualities of valence and arousal, the drumming condition shows greater activity than the talking condition in two loci, one in each hemisphere, mapped in accordance with the NIRS-SPM atlas (Mazziotta et al., 2001; Tak et al., 2016). The right hemisphere peak voxel was located at 62, -36, 28 (T=5.32, p<0.00001, p<0.05 FDR corrected), and it included supramarginal gyrus (BA 40) 41%, superior temporal gyrus (BA 22) 25%, and primary somatosensory cortex (BA 2) 21%. The cluster in the left hemisphere had a peak voxel at -66, -30, 30 (T=3.78, p=0.00030, p<0.05 FDR corrected), spatial distribution including primary somatosensory cortex (BA 2) 42% (BA 2) and supramarginal gyrus 20% (BA 40).

Cross-Brain Coherence Comparison between Monologue and Dialogue Drumming. Cross-brain coherence was compared between the monologue and dialogue drumming conditions. Hemodynamic signals were decomposed into frequency components, removing low-frequency task effects and revealing fine-grain temporal oscillations used to compare synchrony across partners. Coherence (y-axis) – the correlation between the simultaneous signals of partners acquired while engaged in the joint tasks of sending and listening – was plotted against signal wavelets (x-axis) represented as periods (secs) in Figure 8. Coherence was greater for the dialogue drumming condition (red) than the monologue drumming condition (blue) at 17-22 sec across right temporoparietal junctions ($p < 0.05$). There is no significant effect when the partners are scrambled.

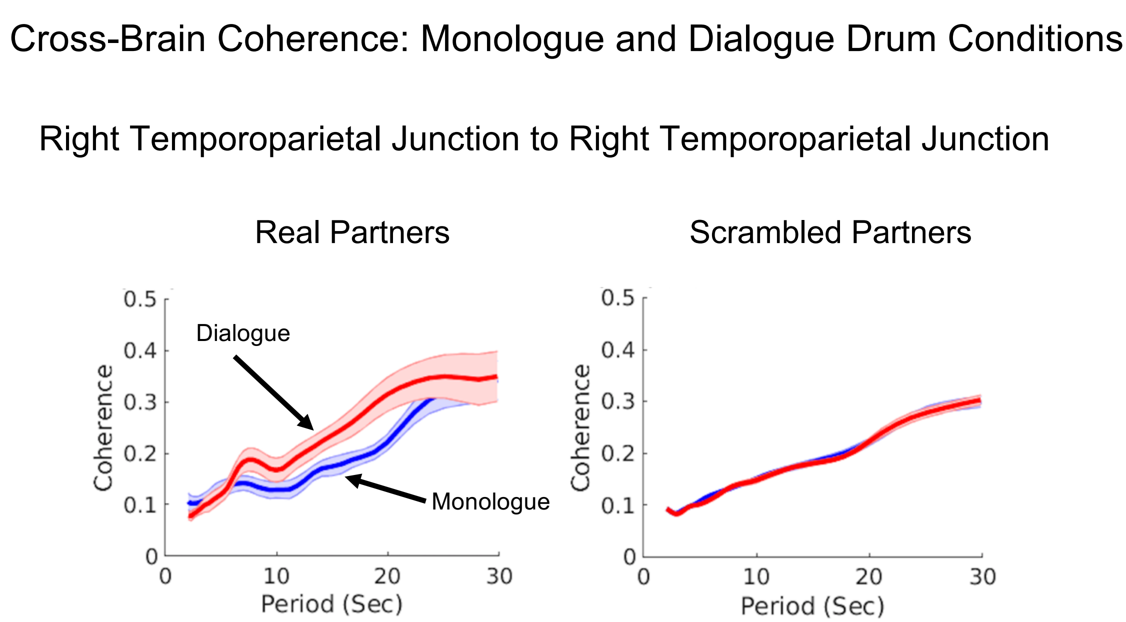


Figure 8. Cross-Brain Coherence for Monologue and Dialogue Drumming Conditions: Temporoparietal Junction and Temporoparietal Junction. Signal coherence between dyads (y-axis) is plotted against the period (x-axis) for the dialogue (red) and monologue (blue) drumming conditions (shaded areas: ±1 SEM). Left: Cross-brain coherence is greater in the dialogue drumming condition than the monologue drumming condition within the range

of temporal periods from 17-22s for signals that originate in right TPJ for both sender and receiver ($p = 0.030$, $t = 1.88$). Right: There is no significant effect when the partners are scrambled.

DISCUSSION

In this study, we aimed to understand the neural mechanisms that underlie the communication of emotional qualities through drumming. Our neuroimaging system using fNIRS and natural interpersonal interaction between dyads enables the study of ecologically valid communication. We hypothesized that strike-by-strike drum measures that communicate expressions of valence and arousal would elicit activity in brain systems associated with social and emotional functions, i.e., the right temporoparietal junction. We also hypothesized that drumming in response to emotional stimuli would elicit neural activity that was distinct from or greater than talking in response to the same stimuli in the right temporoparietal junction. Finally, we hypothesized that cross-brain coherence for "dialogue" drumming would exceed cross-brain coherence for "monologue" drumming in the right temporoparietal junction.

Using behavioral measures, we identified that increased frequency and amplitude of strike-by-strike drum behavior was positively correlated with image arousal and negatively correlated with image valence. We also found that increased frequency and amplitude of strike-by-strike drum behavior was correlated with sensorimotor activity in the "sender" but TPJ activity in the "listener." Taken together, these findings support the conclusion that communication of emotion via drumming engages the right TPJ, and that drumming may communicate both arousal and valence with some preference for arousal. Finally, we observed a greater cortical response in the drumming condition than in the talking condition at the right temporoparietal junction (TPJ), including superior temporal gyrus (STG) and supramarginal gyrus (SMG), suggesting that drumming not only activates this social-emotional brain region, but may have a distinct advantage in activating this area over talking.

Communicating Arousal and Valence. Specific features of drumming may explain its capacity to communicate arousal and valence, with some preference for arousal. In speech, various prosodic features are known to cue emotion, including loudness, rate, rate variability, pitch contours, and pitch variability (Banse & Scherer, 1996; Ilie & Thompson, 2006; Juslin & Laukka, 2003; Koike, Suzuki, & Saito, 1998). Similarly, such features in music include tempo, mode, melodic range, articulation, loudness, and pitch (Eerola, Friberg, & Bresin, 2013; Gabrielsson & Lindström, 2001; Juslin & Laukka, 2003; Jonghwa Kim & André, 2008). Prior studies across both speech and music suggest that cues like articulation, loudness, tempo, and rhythm tend to influence arousal, while mode, pitch, harmony, and melodic complexity influence valence (Gabrielsson & Lindström, 2010; Husain, Thompson, & Schellenberg, 2002; Ilie & Thompson, 2006; Jonghwa Kim & André, 2008). Drumming has limited pitch or melodic capacity; on the other hand, cues like tempo, loudness, and articulation are easily enacted through drumming, and these have been shown to allow a listener to reliably identify particular emotions via drumming (Laukka & Gabrielsson, 2000).

The Importance of the Right Temporoparietal Junction. The right TPJ, including the superior temporal gyrus and supramarginal gyrus, is well established in its social and emotional function (Carter & Huettel, 2013). In a recent example using dual-brain fNIRS, the right TPJ has been directly implicated in functional connectivity during human-to-human versus human-to-computer competitive interaction, consistent with dedicated human social function (Piva et al., 2017). The Superior Temporal Sulcus and Gyrus were an early hypothesized node in the social network (Brothers, 1990), and this was substantiated by later research (Allison, Puce, & McCarthy, 2000; Frith, 2007; Pelphrey & Carter, 2008). For example, this region appears to play a role in interpreting biological motion to attribute intention and goals to others (Adolphs, 2003; Allison et al., 2000), consistent with the Theory of Mind model of the temporoparietal junction.

The social role of the STG has been further investigated within the context of emotion (Narumoto et al., 2001). Robins, Hunyadi, and Schultz (2009) observed increase right STG activation with emotional stimuli; this was especially increased for combined audio-visual stimuli as opposed to either audio or visual stimuli alone, highlighting the importance of the right STG in processing emotional information in live, natural social interaction. In terms of specifically auditory stimuli, Leitman et al. (2010) also observed greater activity in the posterior STG with increased saliency of emotion-specific acoustic cues in speech, and Plichta et al. (2011) observed auditory cortex activation (within STG) that was modulated by extremes of valence in emotionally salient soundbites. Still more relevant to our investigation, the emotional processing of pleasant and unpleasant music has been lateralized and localized to the rSTG (Blood et al., 1999; Zatorre, 1988; Zatorre et al., 1992). Although drumming does not have the same range of affective cues as other music, our investigation replicates the known sensitivity of rSTG to emotion in music through fewer cues like tempo, loudness, and rhythmic characteristics.

The supramarginal gyrus, the other region of the TPJ that plays a significant role in our findings, has also been implicated in social and emotional processing. Activity in the SMG has been associated with empathy and understanding the emotions held by others, suggesting a process of internal qualitative representation to facilitate empathy (Lawrence et al., 2006). Further, there is increased SMG activity particularly on the right side, when one's own mental state is different from the mental state of another person with whom we are empathizing (Silani et al., 2013).

Together, this may inform the relevance of greater TPJ activation in drumming than talking. As hypothesized, this may be a result of the capacity to focus neural processing on social and emotional dimensions rather than the added semantic dimensions of talking. This may also be a result of increased cognitive effort to derive meaning from a "leaner" data source, i.e. without the simultaneous semantic information. Finally, given the importance of TPJ activity in the attribution of intent to visualized motion, our results may reflect the processing of greater visual information in the drumming condition than in the talking condition.

The TPJ is relevant from a clinical perspective as well. In particular, the STG has been increasingly studied in patients on the autism spectrum given the deficits of both language and social interaction. Decreased capacity to attribute the mental states of animated objects in autism spectrum disorder has been linked to decreased activation of mentalizing networks, including the STG (Castelli et al., 2002). Many other autism studies have shown abnormalities in the rSTG, both functional (Boddaert & Zilbovicius, 2002) and anatomical (Casanova et al., 2002; Jou et al., 2010; Zilbovicius et al., 1995).

Volume loss of rSTG has been noted in those with criminal psychopathy (Müller et al., 2008), perhaps underlying their abnormal emotional responsiveness. Volume increases in rSTG on the other hand have been demonstrated in pediatric general anxiety disorder (De Bellis, Keshavan, Shifflett, et al., 2002), in subjects exposed to parental verbal abuse (Tomoda et al., 2011), and in maltreated children and adolescents with PTSD (De Bellis, Keshavan, Frustaci, et al., 2002).

Significance of Brain-to-Brain Synchrony. A new theoretical framework proposes that synchrony between communicating brains is fundamental for successful live communication. The extent to which signals between two interacting brains are synchronous has been reported as a metric of social connectedness between dyads. For example, measures of neural coupling between signals across brains of speakers and listeners who separately recited narratives and subsequently listened to the passages, using both fMRI (Stephens, Silbert, & Hasson, 2010) and fNIRS (Y. Liu et al., 2017), were correlated with levels of comprehension. Cross-brain synchrony associated with other live interpersonal interactions has also been demonstrated, including cooperative and competitive task performance (Dommer et al., 2012; Funane et al., 2011); game playing (X. Cui, Bryant, & Reiss, 2012; N. Liu et al., 2016; Piva et al., 2017; Tang et al., 2016); physical imitation (Holper et al., 2012); dyadic or group discussions (Jing Jiang et al., 2015; J. Jiang et al., 2012); synchronization of speech rhythms (Kawasaki et al., 2013); cooperative singing or humming (Osaka et al., 2014; Osaka et al., 2015); gestural communication (Schippers et al., 2010); and eye-to-eye vs eye-to-image interactions (Hirsch et al., 2017). All contribute to the advancing theoretical framework of cross-brain synchrony as a biological component for reciprocal cross-brain interactions. A hierarchical model of synchronized activity (Hasson & Frith, 2016; Hasson et al., 2004) proposes that different levels of interaction (perceptual, cognitive, and abstract) are associated with specific temporal coupling, and advance an approach for analysis of brain-to-brain coupling using localized wavelets that takes into account the different times scales of putative parallel neural processes and their origins. Non-symmetrical (i.e., simultaneous "sending" and "receiving") communication interactions test for high-level cross-brain interaction effects because processes that underlie both communication production and communication reception mechanisms are dynamically coupled. In this case, coupled neural activity between "sender" and "receiver" reflects a similarly aligned temporal neural pattern during interaction, suggesting cross-brain information transfers are associated with these common timescales of multi-layered neural processes. Our own findings demonstrating greater cross-brain coherence in dialogue than monologue drumming in TPJ areas provide evidence of such non-symmetrical yet coupled processes, and it may suggest greater social connectedness between dyads in this more interactive condition. Such insight may have useful implications for implementation of drumming in clinical settings.

Clinical Application of Drumming. Music and music therapy have been used in a number of clinical contexts, particularly emotional and behavioral disorders such as schizophrenia (Peng, Koo, & Kuo, 2010; Talwar et al., 2006), depression (Erkkilä et al., 2011; Maratos et al., 2008), and substance use disorders (Baker, Gleadhill, & Dingle, 2007; Cevasco, Kennedy, & Generally, 2005). Music therapy is perhaps best known for its utility in autism (Møller, Odell-Miller, & Wigram, 2002; Reschke-Hernández, 2011; Srinivasan & Bhat, 2013), where it has been used to improve emotional and social capacities (Jinah Kim, Wigram, & Gold, 2009; LaGasse, 2014). Given the aforementioned rSTG abnormalities in autism as well as our rSTG results, further research should explore neural correlates and possible neuroplastic effects of music interventions for social and emotional development in autism. Perhaps this may explain the consistent inclusion of drumming in autism music therapy, and the special attention paid to rhythmic and motor aspects of music in autism (Srinivasan & Bhat, 2013; Wan et al., 2011).

However, while drumming has a number of musical elements and is often a part of group music-making, drumming and music are not identical. While music has been well established to cue both arousal and valence, we demonstrated the capacity for drumming to communicate arousal better than valence. This suggests that drumming interventions may be more effective for psychopathology typically associated with arousal (e.g. anxiety disorders, like post-traumatic stress disorder) than for psychopathology typically associated with valence (e.g. mood disorders, like depression). This is substantiated by some preliminary work using drumming for individuals who have experienced trauma (Bensimon, Amir, & Wolf, 2008; Burt, 1995).

Limitations. Limitations of fNIRS investigations are balanced with advantages that enable dual-brain imaging in live, natural, face-to-face conditions. This study is the first to our knowledge to investigate the neural correlates of nonverbal auditory communication of emotion in an ecologically valid setting. One unavoidable limitation is the restriction of fNIRS data acquisition to cortical activity, due to limited penetration of infrared light through the skull. This excludes important limbic and striatal structures, which are known to be active in musical induction and perception of emotion (Blood & Zatorre, 2001; Brown, Martinez, & Parsons, 2004; Koelsch, 2010; Peretz, Aubé, & Armony, 2013).

In terms of our behavioral data, while we noted a correlation between drum response and both arousal and valence, the negative correlation observed between drum response and valence may actually be due to arousal. The arousal and valence distributions of our IAPS subset (Fig S1, Supplementary Materials) indicate a relative lack of images with low valence and low arousal. This bias, which reflects a similar bias in the complete IAPS image set, results in an overemphasis of low valence images with high arousal, potentially mediating the negative correlation observed where drum response increases with lower valence.

In the comparison of drumming and talking conditions, we recognize that the elicited region of greater TPJ activation in drumming likely contains some contributory activation from nearby SMC, as expected from a drumming task. That said, the higher probability of TPJ regions noted by our digitizing process, as well as the breadth and significance of the observed neural activity in this area, provide confidence that there is a strong component of TPJ activation in drumming over talking. This speculative result invites further investigation into the utility of drumming over talking as communication modality with clinical application that elicits social-emotional engagement.

Further, our fNIRS subject population of mostly college students may limit generalizability. In particular, while drum experience was very low, there was a moderate level of averaged musical expertise that may have facilitated subjects' drum communication of emotion (Methods, Table 1). Further research should replicate these results in both a drum-naïve and music-naïve population.

GROUP DRUMMING INVESTIGATION

INTRODUCTION

Group Drumming in Therapeutic Settings. Drum circles and other forms of group drumming have found their way into a number of therapeutic settings. There has been a significant amount of research investigating group drumming for youth, particularly alienated, low-income, and at-risk youth (Bittman, Dickson, & Coddington, 2009; Currie, 2004; Faulkner et al., 2012; Ho et al., 2011; Sassen, 2012; Snow & D'Amico, 2010; Wood et al., 2013). All of these studies suggest social and emotional improvements, particularly regarding stronger community, better social relationships, increased empathy, regulating anger and aggression, improved self-esteem, and significant changes in measures of depression, anxiety, and attention deficits. In adults, group drumming interventions have been used as adjunct therapy for substance use treatment (Blackett & Payne, 2005; Winkelman, 2003), trauma and PTSD treatment (Bensimon et al., 2008; Burt, 1995), broader mental health recovery (Ascenso et al., 2018; Longhofer & Floersch, 1993; Perkins et al., 2016), and general wellbeing for various healthy populations, including university students (Mungas & Silverman, 2014) and social workers (Maschi, MacMillan, & Viola, 2013).These studies highlight various uses and effects of group drumming: feelings of belonging and community, a sense of empowerment, a safe environment for learning, a place of expression and generation of energy, mood improvements, and stress reduction. Unfortunately, however, there has been almost no research on adult incarcerated populations, with the few studies suffering from single-event workshops rather than consistent programming (Eluyefa, 2015), or working only with very specific populations like adult sex offenders (Watson, 2002) or Aboriginal women in the context of traditional ceremony (Yuen, 2011). This dearth of literature is despite the fact that individuals who are incarcerated sit at the intersection of many other populations who have received benefits from group drumming; they may receive particular benefit given their high levels of PTSD and trauma history (Carlson & Shafer, 2010; Dierkhising et al., 2013; Honorato, Caltabiano, & Clough, 2016), substance use disorders (Fazel, Bains, & Doll, 2006; Mumola & Karberg, 2006), and other severe mental health disorders (Fazel & Danesh, 2002; Fazel & Seewald, 2012).

Study Overview. This investigation sought to explore the benefits of group drumming in a carceral setting, namely a halfway house work-release program in which individuals complete their sentence and reintegrate back into the community. In this halfway house, residents undergo various groups for processing and for assisting in job finding and preparation. They are permitted to leave for several hours each day to search for jobs, go to their job(s), or attend other authorized events (e.g. medical appointments, religious services). As residents are allowed to leave for several hours, it is not uncommon that they choose not to return, thus “escaping” the program without completion of their prison sentence. This often results in serious consequences if they are found and apprehended, such as a return to prison and/or an increase in length of sentence. This suggests halfway house retention rate as a point of interest in this study.

In this primarily qualitative investigation, participants randomized to the group drumming intervention (versus treatment as usual) were interviewed after implementing an eight-week group drumming intervention to understand their self-reported experienced benefits. Informed by current literature on similar interventions, we hypothesized social and emotional benefits. However, in alignment with rigorous grounded theory methodology, we avoided further specificity of hypotheses regarding participant responses to limit bias in coding and thematic analysis. Quantitatively, this study investigated the impact of group drumming on halfway house retention. As a secondary aim, this study also sought to address the feasibility of implementing a group drumming intervention in a carceral setting.

METHODS

Participants. Twenty-eight (28) healthy adult men (mean age 38.4 ± 11.4) participated in the study. All participants were recruited through flyers and a single information session at each of the two participating halfway houses in the same building in New Haven, CT. The halfway house residents consist entirely of adult men completing their prison sentence through this reintegration program in which they either look for employment or work at a job they have recently obtained. All participants provided written informed consent in accordance with guidelines approved by the Yale University Human Investigation Committee (HIC # 2000022265) and were reimbursed for participation. These participants were then randomized to either a treatment as usual with Drum Group intervention arm or a Treatment as Usual control arm. All participant recruitment, consenting, randomized group assignment, and reimbursement were conducted by the author.

Table 2. Group Drumming Study Demographic Information

Category	Subcategory	Total / Avg	Drum Group	Treatment as Usual
N[A]		28	14	14
Age		38.4 ± 11.4	39.7 ± 12.9	37.1 ± 9.9
Race				
	Black / African American	11	7	4
	White	2	2	0
	Other	12	4	8

[A]Demographic data missing for three participants (one in Drum Group, two in Treatment as Usual)

Intervention. The Drum Group intervention consisted of a weekly group drumming session, with each session running for approximately one hour. The intervention ran for eight weeks in February and March of 2018, with each session facilitated by a certified

Music Therapist and professional drummer. These sessions took place in the building's gym, internally accessible to participants from both halfway houses. Of note, while the intervention relied primarily on group drumming (free-form, call-and-response, supported solos, facilitated learning), it also included the use of "tone bars," elements of vocal expression, co-creation of a song to which the facilitator played keyboard, and discussion and reflection often stemming from the lyrics of a song that participants drummed along to. The intervention was developed by the facilitator that the author recruited, with some direction and parameters from the author.

Quantitative Data

Attendance and Retention Rate. Data was collected each drum group session on participant attendance, including reason for absence. Retention rate was also collected and compared between the drum group and the treatment as usual group. As these data were collected evaluate the potential effect of drumming on participant's engagement with treatment and reintegration, lack of retention was defined by "escaping" the halfway house, i.e. leaving and not returning, rather than successful completion of required time in the halfway house or official transfer elsewhere.

Qualitative Data

Data Collection. Interviews were conducted with all study participants (drum group and treatment as usual group) in a private room in the halfway houses upon completion of the drum group intervention. While these semi-structured interviews covered a broad range of topics integral to participants' lives and experience in the halfway houses, this study focuses on the drum group participants experience of the group drumming. Consistent with a phenomenological approach, broad, open-ended questions were followed by probes to gather in-depth descriptions of participant experiences. Consistent with grounded theory methodology (Glaser, 1992; Strauss & Corbin, 1990), data collection and analysis were iterative in nature, such that the interview guide evolved to better capture the emerging themes from participant experiences. A focus group to discuss the experience of being in the drumming group was also conducted upon completion of the intervention. All interviews and the focus group were conducted by the author.

Data Analysis. All interviews and the focus group were audio-recorded and then transcribed by the author, another collaborator, and an external transcription service. Initial code generation was completed separately by the author and two collaborators through a process of in-depth open-coding of the first few interviews. The author and these two collaborators then applied their initial code set to the rest of the interviews and focus group, iteratively editing the code set. They all met to discuss discrepancies, points of confusion, redundancies, and omissions. Differences were negotiated, resulting in a comprehensive codebook that the author and both collaborators then applied to the whole set of qualitative data. A second meeting was conducted to refine the breadth, depth, and clarity of the final codebook, and then key themes were identified and discussed. The author then continued to refine the themes and their interrelationships, reviewing transcripts to verify and supplement key findings. Throughout this process of data analysis and group meetings, the author wrote analytic memos to guide analysis and theory development, and the author also met regularly with a faculty sponsor (an experienced qualitative researcher trained in phenomenology) to discuss codes, emerging themes, and obstacles in the analysis process. The qualitative analysis software Dedoose was used by the author and other two analytic collaborators throughout this process.

RESULTS

Quantitative Results

Drum Group Attendance. Fourteen people were assigned to the drum group; one of these participants quit. Of the thirteen participants who completed the drumming group, average attendance for the eight sessions was 6.9 ± 1.1 (86.5%). Of the fourteen total absences, eleven (79%) were due to work, starting the program late, or successfully completing their time in the halfway house.

Halfway House Retention. Of the 28 total participants, five participants (17.9%) chose to leave the halfway house without completing their sentence ("escape"). The retention rate in the Treatment as Usual Group (63.3%) was significantly lower than that of the Drum Group (100%), $p = 0.019$ (Fig 9).

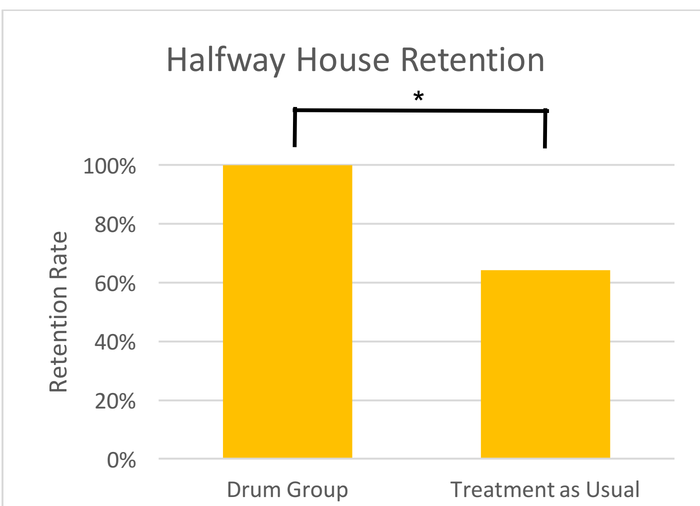


Figure 9. Halfway House Retention. The retention rate in the Drum Group (100%) was significantly greater than the retention rate in the Treatment as Usual group (64.3%), $p = 0.019$.

Qualitative Results

Qualitative data coding and thematic analysis resulted in the identification of three overarching themes. First, group drumming functions therapeutically as a method of coping with difficulty. Second, group drumming offers opportunity for connection through building relationship and experiencing communion in a setting where isolation is the norm.

Theme 1: Coping with Difficulty

Group drumming functions therapeutically as a method of coping with difficulty.

Expression to Relieve Stress. Every participant described ways in which the drum group helped them in coping with difficulty. This occurred through distraction, a “meditation” or “out of this place”-type effect, a sense of escape or freedom, or direct improvement in mood. Almost always, this began by naming an experience of relieving or reducing stress.

> When it came down to Sunday… I [was] like, okay, got the drum class coming, so, kinda like, you know, knew and knowing that whatever you might've going through with that moment, or week prior or whatever, going there and it'll, be released a little bit, you know? Whether you were tensioned about something or you were upset about something, you're stressed, and, but going there and just kinda relieving yourself and just being, cool and calm, and just playing some music… Let it go a little bit. (Participant 4, age 40)

The reduction of stress was often tied to these two concepts noted above: 1) “relieving yourself,” and 2) “let it go.” The first implies using the drums to get out the stresses, suggesting some form of communicating them through drumming in a way that releases them. This is reflected in other participants language about being able to literally “beat my… troubles… my stress” (Participant 2, age 50), “to let out something” (Participant 12, age 29), “to get a lot of things out” (Participant 8, age 54).

Letting Go and Distraction. This expression in turn seems to create the space to “let it go.” Drumming was therapeutic or stress-relieving in part because it facilitated a process of letting go of negativity, such that stresses were forgotten. This letting go or forgetting occurred for many participants without needing to explicitly “relieve” or express the stress. After naming several current stressors, one participant went on to describe this effect:

> In the hours that we spent, you know, in there doing all this… I wasn't really thinking about nothing negative or anything like that, you know what I'm saying? It was like, therapy to my mind. And, when you guys, leaving now an hour after that, I said, you know, everything's over now, you know, now we gotta wait til next week, you know. But yeah, I think, you know, my way to thinking and, and, and...for some reason you always relieve some kind of stress, you know, whatever you feel inside you're getting through it, you know, you forget about things. And, about, if you had a bad day I'm pretty sure, well for me, I think it was, I forgot about it, really, you know what I'm saying? And, had, a different way to thinking. And, the way I feel when I left, you know, the room once everything was over, you know, I felted different. Way different. [It helped me] to relax…to distract myself. (Participant 6, age 61)

This “forgetting” of stressors and negativity typically happened through a process of distraction, as described above. In the focus group, when one simply said, “It was a positive distraction from the negatives that are around” (Participant 13, age

47), multiple others nodded or stated their agreement. For some, this distraction functioned as a coping mechanism because it took the edge off high level emotions like anger or stress. The following individual described this effect by connecting it to his experience with music more generally as a coping mechanism.

> Yeah. [The drum group is] a good distraction. It ends up becoming a good distraction because kind of like I've always said before, when things were going awry, I get pissed off. In my house, I go and lock myself in there. I turn on the music and before you know it, I'm so caught up with what was going on that hours went by. You know what? It's not longer an active problem… the more you stay in the problem, the more chances of something else arising on it. (Participant 13, age 47)

Thus, using drumming or other music becomes a way to reduce the negative affect associated with an experience, in turn reducing the chance of it growing into a larger problem.

Meditation: In the Present or Far Away. Some participants further described this distraction as more than a way to take attention away from the negative; it was also important to note where attention was placed instead. One participant connected the experience to yoga and mindfulness workshops he had in prison, highlighting this as a way to shift attention from the negative to "the present."

> Same thing. Because, the drumming, you have to be mindful of that music, you got to be mindful of that rhythm. So you have to be aware of that moment. So, it's pretty much, it's mindfulness. It's a different form of meditation… Because you're caught up in that moment. You're not thinking about nothing else, you know, what other problems you got, whatever, whatever. You focusing on that. You focusing on the drumming. You're focusing on the rhythm. You know what I mean? And that's what it is. You're expressing yourself. A different form of meditation. (Participant 1, age 35)

Multiple other participants similarly described the drumming group as “meditative” or “like meditation,” typically still within a context of coping. Interestingly, in contrast to the rhetoric of being in the present moment, other described the meditative coping experience of drumming as taking them “out of this place,” far away from the present situation. This was one participant’s response to how it helped him deal with anger.

> That drum. The drum is like meditation… Yeah notice when I be in there, I just be listening. Sometimes, it's, I'll be in the zone. You think I'll be sleeping, I'm not sleeping. I just be meditating, I mean. Yeah I'm in a whole different world. I'm like I'm in Africa when I be hearing that music, certain music, or you know, or I'm in Jamaica, or, I'm in somewhere I'm in another country. Far away. And that music just take me there. (Participant 5, age 48)

Escape to Freedom. Others illustrated this same effect of taking one away from the negative, without the “meditation” framework. This was often framed instead as release or escape, like one participant who said “the drumming was actually my getaway car. So that whole hour, I took advantage of, man, I felt free” (Participant 3, age 27). Importantly, this particular phenomenology of a sense of “freedom” was reflected by many participants as a direct contrast to their daily life that allowed them to deal more effectively with their daily stressors. This freedom was a freedom from shackles of negativity, thus a type of stress relief that extended beyond mere distraction.

> Freedom. It made me feel free from all this mad… chaos. You know what I mean? It takes, it takes that right out of, out of my mind, out of my, out of my spirit. You know, I think all, everybody has this aura about you, and you, and you let, you let that bad stuff come in… And maybe you have a bad feeling about your roommate, or you, your girl, or you going through some trouble trying to find a job everything. When we go to the gym and we do

> [the drum group], none of that, none of that matters, you know? None of that matters and that's what I like about it… It's that freedom man, and nobody else can take away from you. You know what I mean? …They can lock me up, they can do whatever they, everything they want to do but, they can't take away that beat in my head. You know? (Participant 2, age 50)

A Positive Shift of Emotion. The participant quoted directly above continued on to discuss this freedom related to feeling good: “knowing that I could do this, and it makes me happy. Something that makes me happy. Making me feeling good” [sic] (Participant 2, age 50). This relationship between freedom from negative affect and the engendering of positive affect was commonly discussed amongst participants. Coping was not just about distraction and forgetting about negatives, or even about paying attention to the present moment. The value was often in the shift of feelings, an actual improvement in mood.

> It made me feel good, like at the end of the day, like, I got to feel a little better, no matter what I was going through. Like I had some fucked-up days, so. You know, just coming kinda made me feel a little better. (Participant 14, age 25)

Per the first quote in this section, the positive affect was described as “cool and calm.” This was further nuanced by others as feeling “relaxed” or “peace of mind.”

> I just felt at peace in that group. I swear, when you didn't have that group last week and we had it Monday, man I was going crazy. I said, "Man, where the heck is [name]?” …It was soothing though. Relaxation. (Participant 10, age 50)

A Lasting Effect. These all indicate a pleasant reduction of some higher arousal state, often stress or anger. For some, this was an effect that lasted beyond the length of the group drumming session. Others felt this as well, particularly for the mood improvement. As one participant put it, “It’ll take you from negative to positive… Then you come back up, you don't even pay attention to the negative. You're feeling good about being with the positive people and then you just go on about your business and get the day over with” (Participant 8, age 54). While this describes the maintenance of a positive mood shift, another participant went a step further in naming that this lasting effect proves useful even when one is reintroduced to stressful conditions.

> When I beat on the drum I, you know, my goal is covered. I feel, I just feel like I'm, I'm just good right now. You know? And, you know it lasts for a while, then it goes away as soon as I start, you start smelling the atmosphere again you was like "oh here we go again with this mess." But that feeling is in here and I know, I know what I good feeling feels like? You know? That experience. That's why I like it… I know if I go out here and I beat on this, this, this, this door or I hit this, you know garbage can, and I beat on it right there my brain would be back there and I'll feel better, you know? (Participant 2, age 50)

After describing how the mood effect lasts beyond the class even with the reintroduction of new stress, this participant also shares a newfound potential for even further lasting effects: he is now equipped with a tool that he can apply in future situations to improve his mood. Drumming now becomes something that can be accessed at will in the future as a coping mechanism.

Theme 2: Connection through Relationship and Communion

Group drumming offers opportunity for connection through building relationship and experiencing communion in a setting where isolation is the norm.

Every participant in the drum group discussed connection in group at various levels. At one level was a behavioral spectrum of relationship that varied from increased interaction to building supportive relationships. On another level was an affective spectrum illuminating the phenomenology of shared positive energy that varied from feeling comfortable to a sense of communion with the group that transcended the individual "self."

"I Just Stick to Myself." Before introducing the various levels of connection, we begin by naming an important backdrop: the relatively common mentality of participants to function independently and alone. Over half of participants said something to the effect of not being very close to others in the drum group or halfway house generally. They were "cordial" and greeted each other, but otherwise felt little motivation to talk to others, that they were "not too much of an open person" (Participant 1, age 35). As another put it:

> I just don't talk to people like that in general… I speak to people, I say what's good all the time, but like I don't, I just actually don't be too friendly. Especially, like, I know for a fact that all y'alls older than me like, y'all gonna go back to you doing you. Cause most of those people in there are way older than me… Like my, my movements is different from yours, so like, it's no disrespect, but it's just like, I know we ain't gonna rock the same way… so I just never felt like going out of my way to talk to them, I'm just not about it. Like, I just stick to myself and stay out of trouble that way too. (Participant 9, age 20)

In addition to this assessment of his own disposition, this participant’s comment about age also suggested that those older than him would go back to illicit activity consistent with their previous actions. The last sentence indicates that more than an issue of personality, sticking to himself was a matter of self-preservation, namely a way to avoid getting caught up in illicit activity. Another participant felt similarly:

> I'm the type of person I don't get too close to too many people around here. The reason [is not] because I don't like them or anything like that, the reason I'm doing this because a lot of people do stupid stuff, you know what I'm saying? And when I see people doing some dumb stuff, you know, I, I try, I try stay to myself, because I don't, I, first of all I don't like to complain about everything and second of all, that, keep me out of trouble… There's much stuff going around and I and I, know you, I came over here to, to look for a job and to do the right thing, and I want to stay that way. You know what I'm saying? (Participant 6, age 61)

Moving toward Connection. Interestingly, more often than not the drum group was considered a separate space from the negative influence of the rest of the halfway house. This complicated the isolating tendencies for many of participants.

> When I'm around people I don't really know, I really don't ... I don't really want to react and correspond with, with people I don't even know. The drum group was quite different. I haven't experienced nothing like that before. (Participant 10, age 50)

One participant named this shift more directly.

> And now, getting closer with the brothers in here that I never talked to, I talk to. You know what I'm saying I stay to myself, so I start[ed] dealing with a lot of brothers that I talk to now. You know? (Participant 5, age 48)

This demonstrates a particular departure from a normalized isolation and “sticking to oneself” toward connecting and interacting with others. The conflict of these two competing energies was evident in the frequency of those describing isolating tendencies to go on to describe connection within the drumming group, sometimes in immediately adjacent comments.

> Interviewer: [Do] you feel like your relationship changed [with] folks in the room?
> Participant: In a way. There wasn't a lot of people from up here [in the upper floor halfway house] down there [in the lower floor halfway house where the drum group was held], but the people that were up here I was already pretty cool with anyway, so… I didn't really say [I] built a connection with some of the other guys from the other halfway house, but I'd say I did a little bit. I talk to some of them here and there now. Some they say hi to me.
> Interviewer: Hmm. And you were about to say the group was helpful with life in some way? What were you saying?
> Participant: By bringing people together. (Participant 11, age 30)

The Behavioral Spectrum: Connection through Interaction and Relationship. The idea of the drum group “bringing people together” was common. On one end of this behavioral spectrum, this was about people getting to “chop it up with people you wouldn’t normally chop it up with” (Participant 12, age 29), i.e. merely people interacting more with each other that they typically would.

> The bonding. It's. We all, it's just us us, certain guys we going in and we look at each other and I used to tell the guys I said "Yo we bout to beat them damn drums today. Beat them drums tomorrow." And they were like "Yeah we bout to do it. We do it." And then at the same time we be like, after we just eating, just laying in the bed, "Oh yeah that's right." (Participant 2, age 50)

Notice that comment indicates interactions that carried beyond the sessions themselves. This was described by several others. One said, “some [relationships did change]… we, we were able to talk to each other, you know, just, just passing by and stuff like that. Being a little more open" (Participant 4, age 40). This is notably in contrast to the difficulty many had in opening up, and it offers the possibility of creating deeper relationships. This possibility is best characterized by two quotes from one participant:

> I get along with, especially like, we started the group, you know, the drum group. And I started getting more, you know, with the, with the guys and everything I talked more to them. I say, "you okay, you need something?" If I got it let me know, you know, I got you." …We all got to stick together, you know. (Participant 6, age 61)

> So now what I, all the guys that were in the drum group, you know, we we like, we stick more… and we talk more, and we, you know, we get along a whole lot more… And that that's that that's the good thing about being in drum, you know, over there, you learn more, you get to know the guys more, you know, we share things. And, you know, it it, it's a good thing, you know? It's a beautiful thing. (Participant 6, age 61)

These quotes point to functional changes in relationship, where the sense of closeness to each other facilitates tangible support. Importantly, these two quotes were punctuated by the earlier quote from the same participant about not getting too close so he can stay out of trouble. Thus, this same participant sees the drum group in direct contrast to the loneliness of the rest of the halfway house, providing opportunity for connection and reciprocated support.

The Affective Spectrum: Phenomenology of Shared Energy and Communion. All of the above point to individual relationships as illustrated by people interacting and behaving differently. The other spectrum framing participant connection within the drumming group was an affective one. Along this spectrum we find descriptions of the experience of shared energy.

> but in there like, it wasn't no negativity, wasn't nothing like "they don't want to leave here," it's like, it's just like, we came here, we drumming, you see people laughing and just have a genuinely good time (Participant 9, age 20)

This individual again notes a lack of negative experience, and then goes on to provide observation of the affect others were experiencing, suggesting a reflection of his own. This is notably one of the participants quoted above as someone who isolated and did not build relationships within the drum group. Even without individual connection, he was still able to experience positive affect in connection with the larger group. Others more directly described their own positive experience:

> Being in a group of people, you know [?], nowadays people really don't come together, like they used to, you know what I mean? So it felt kinda like, a little empowering a little bit, you know everybody got along and together, everybody was in sync, even though it took a little bit, but we had fun with it. (Participant 4, age 40)
>
> The group was a good group, and everybody in the group, each and every one of us, we practiced until we got it, and it really feels good to see how a group participates together, and stay in rhythm and stay in sync. (Participant 8, age 54)

Notice here that even when talking about people coming together and playing "in sync," these descriptions highlight a particular phenomenology: the experience of shared energy that engendered positive affect. Such descriptions were common and ran the spectrum from “feels good” to experiences of something collective that was bigger than self. One participant used the word “spiritual” to describe the group, and then elaborated:

> Interviewer: What felt spiritual to you about it?
> Participant: You really want to hear it? It's, it's the circle. You know? And then how [the facilitator] has us playing certain parts sometimes you know, and just beating the drum, feeling like you belong… It was a good feeling. (Participant 2, age 50)

This “spiritual” phenomenology was directly connected to a feeling of belonging, suggesting a sort of experienced communion. One other individual also used the word “spiritual,” and similarly related this to group communion through being in sync: “We were just there playing music and communicating and it's just, all were in sync at times, you know what I mean? And I, felt pretty good” (Participant 4, age 40).

This was taken a step further by a few individuals who described this is a unifying experience, for instance: “This group made me feel more alive. Beating on the drums. Instead of just listening to music, I became the music, we all became the music together” (Participant 11, age 30). Such unity transcended the sense of self: “everybody just be together as one” (Participant 5, age 48).

Relationships to Friends and Family. In the realm of drumming for connection, another emerging subtheme elucidates how the drum group facilitated connection not just amongst participants but also with family, friends, and significant others. Note how some of these comments suggest future action that may function to deepen these relationships.

I told my girl like, this is what's gonna be the last day of this group. And she's like so you know one night you gonna, you'll do a little beatin for me? She says I'ma get you a little drum. I'm like are you serious? She's like ya seriously, I'd like to see what you learned in that class! And see, and I told my family, I told my mother I told my sisters and all of them they're like, okay, little brother's a little drummer okay! You nah mean, cuz I'm the little one. So ya, it might be something down the road you know. (Participant 10, age 50)

My niece got a church, I can help her with her church and get into a little, write some music to the church. You know? Now I can play bongos or drums or whatever that will help out with the music in her class, in her in her church. (Participant 5, age 48)

Theme 3: Personal Growth toward Re-Humanization and Self-Empowerment

Group drumming provides an environment for personal growth, particularly toward re-humanization and self-empowerment.

Re-humanization through Treatment. Almost every participant discussed some level of personal reflection and growth through the drumming group. At the most fundamental level, this began with seeing themselves as more than prisoners or convicts— rather as full human beings. In expressing their gratitude for the group, it is clear that many saw themselves first and foremost as “ex-cons” or “ex-felons,” and consequently underserving of receiving what was offered.

> [You all] care[d] about what people do in here. You know? You guys didn't need to do that. You know what I mean? So that right there showed me that these strangers are really taking their time out of their busy lives to meet us, other strangers, ex-cons, or ex-felons, or whatever and give us the opportunity to express ourselves through music. So that right there is big, because y'all didn't have to do nothing, such a thing. (Participant 3, age 27)

Hence, the process of creating a space where they were treated as more than that was especially appreciated, and participants placed this in direct contrast to how they experienced the prison system.

> You took the time out of your life to come and do this and try to see what it would benefit for these guys. That's something that a lot of people don't do anymore. A lot of people don't come here and ask us our opinions. I've never heard of that… I think that it should get recognized more because a lot of shit that these guys go through and myself went through in jail is not ... It's not very healthy. When you're in jail, they really don't give a fuck about you. (Participant 14, age 25)

This participant quoted directly above went on to describe a vivid story of staff neglecting a prisoner’s injury in order to illustrate just how dehumanized they were. In highlighting the contrast, another participant compared the drum group to a rare experience of humanization through a yoga and meditation class while in prison.

> When I was in meditation and when I was in yoga, that hour and half, you totally forget you was actually incarcerated. You know? And the instructors were so awesome. It's that...they didn't treat you like an inmate. They treated you like a person… Treat people like people, not like, you know what I mean? Inmates. Treat people like people. You know what I'm saying? Because, you know, a lot of people, like I said man, we're just coming into society. We've been dehumanized for so long. You know what I'm saying? So to be actually treated like a human being, you know, it's a good feeling. (Participant 1, age 35)

One participant described this “good feeling” of being humanized as “freedom,” associated simply with being heard.

> It's like a freedom. It was like free. You know? Where we all could talk when we all could be heard. You know? So, I was like. This, this is, this is something really good for me because, well it's good for all of us but like for me, I'm always seen, you know like children always seen but never heard? That's the same for, we always seen, but when it's time for us to be heard… I'm just getting to the point that, you know, we have an opportunity to be heard and I think if we stand behind that drum thing, we keep it moving, I think it'll be something more of a spiritual movement. (Participant 2, age 50)

Re-humanization through a More Complete Self-Narrative. Of course, this re-humanization did not all come from the drum group facilitator. For many, the drumming group put participants in touch with other identities and broader personal experiences. For example, as one person stated, "It helped me reconnect with the music side of myself” (Participant 13, age 47). Another reconnected it to childhood experiences playing the drum:

> [The drum group] helped me to not forget where I came from, as far as playing drums and stuff like that… Because I learned from going from school. That's how I learned the drum lessons from school… I started with the band and stuff like that. I've still got pictures and all that stuff. I don't have them on me but she has them down there, down south. Pictures of me in parades… (Participant 8, age 54)

And participants did not need to have personal drumming experience to use the drum group to draw connections to their life. The stated importance of music in their lives was ubiquitous, regardless of any history playing music, and this is what made the drums meaningful and accessible. Some said it reminded them of experiences with ago-go junkyard backyard music in DC, or of the islands that they knew the drums and reggae music came from. For many, it elicited a childhood memories:

> I grew up, you know like every… every weekend guys [got] together in [city] the park, and I used to go with them and see the guys play, you know, the bongos, and another one with guitar, and, one time back in the '90s, you know, I used to drink beers, so, you know, everybody having good time and they say, you know, people sing...and I didn't participate, in on it, but I was right there, you know, listening to the guys and the way things sounds, and. You know, it was... and it's me now, you know, I said, maybe when I get out, I I, like on the weekends for the summer maybe I'll try to do something positive like [that] (Participant 6, age 61)

This quote exemplifies a timeline of identity and change: he connected to a lost past, learned a related skill, and then suggested a future endeavor where this skill made his connection to music more tangible.

Drumming for Empowerment: Nurturing Motivation. The above participant's ability to see a new possibility for his future was directly tied to what he felt he could actually do in this future, implying a new sense of self-empowerment. Such self-empowerment was the most potent emerging theme related to personal growth in the participants' experiences. And while the above example was directly about playing drums, most people experienced the drumming group as motivating and empowering more generally: The drum group "just made me wanna move forward with things in life… Just by getting active and being involved in other things" (Participant 11, age 30). Or even more broadly:

> Motivation. A new way of motivating your mind, body, and soul. A new way of motivating yourself within yourself while we here, that'll keep our body and self and know a different level where we need to be. (Participant 5, age 48)

For some, this happened through an explicit process of self-reflection that the drumming group incited. After one session, one participant went back to his room and journaled about what was coming up, which he read aloud in his interview.

> Dear Journal, the way I've been feeling lately, it's hard to put into words. I have so much going on in my life that I feel that sometimes, I can't keep, keep going. And no, I'm not saying that I want to die, or take my life. Life is a beautiful gift from God. If you believe in God. What I'm saying is, since there's so much on my plate, I sometimes feel of feeling back and giving up. But why do such a thing? It's crazy, right? Makes no sense. And why I feel the way I do. I guess it's because everyone is counting on me to do what must be done. I usually a happy content joyful person, but lately, it's not me at all. I try to look at the bright side of things, and remind myself that everything will be okay. But the way things seem, it feels like it's not. But I have too much to lose. About four years ago I committed an act that brought me inside a dark place. And in that dark place I felt alone, scared, and betrayed. So I fought my back to the light. It took my a while to do so because along the way I bumped into many dark and negative people. I fought many battles, especially battles within myself. Battles that drained me mentally and physically, but I was very determined to win. To not give up. I have too much to lose. (Participant 3, age 27)

This eloquently captures the motivational effect of the drum group. Note again how it emphasizes determination, winning (especially internal) struggles, and an appreciation of how much he cannot afford to lose. It literally stirred in him a sense of empowerment to make changes in his life.

Drumming for Empowerment: Nurturing Agency. For other participants, manifestations of self-empowerment came through more clearly through behavior rather than reflective statements. Multiple participants noted that the drum group – particularly drum solos and vocal components – helped people open up and overcome shyness. One participant actually got up and began to facilitate the drumming group on his own during a class; in describing this experience, note how he names both how it felt and how it encouraged others to do the same:

> The class where I took over a little bit… That was pretty cool. I was trying some beats. It started with me…It made me smile. The other guys enjoyed it when I did that. They enjoyed it and then they did it too. It was pretty cool. You get a group of guys who are struggling obviously with where they want to be in life right now. Trying to better themselves and do something in a group together. (Participant 3, age 27)

He connected how he inspired others to get up there with statements about people trying to better themselves, suggesting this relationship between self-empowerment within the drum group and improving one's life generally. Others did in fact follow after him, and this was not actually by the invitation of the actual drum facilitator. It naturally occurred in one of the later classes, speaking to the growth and confidence that built over time.

Finally, not all behavioral change around self-empowerment is about what could or did happen; what did not happen can be equally if not more important. One participant shared the influence of the drum group on mitigating his desire to leave the halfway house without completing his sentence (i.e. “escape”):

> When I got into the drum group, I talked about leaving twice already, and then I was talking to [staff member], I think yesterday morning and today and letting him know. You know what I'm saying? Like I said, I said, "The drum group on Sundays helps me to really stay here." (Participant 8, age 54)

This participant explained in detail his frustrating situation and reasons he should not have been in the halfway house to begin with. These frustrations were named well before the drumming group started, and he described how he had chosen to “escape” from the same halfway house in years past. His choosing not to do this again was noted as a big step for him. In the focus group, he described to the group what was different:

> I'm glad this drum program, I'm glad it really did happen. Because there's certain things that I had on my mind, I probably woulda left this halfway house, but, I can say that me standing here and wanting y'all to here that, "oh ya, he left the program, this halfway house," I don't wanna, you know what I'm saying, I don't even wanna go through that. You know what I'm saying, cuz right now I'm tryna be strong and *deal* with this. I was supposed to be home four weeks ago, but I'm trying to really, really deal with this right now. (Participant 8, age 54)

His motivation and empowerment not to leave was notably tied to a felt sense of accountability to community, in spite of all the stressors he was struggling to cope with. This provides a concrete example that might explain the quantitative findings, and it illustrates the inextricability of the emerging themes: drumming to cope with stressors, find connection, and facilitate personal growth and empowerment.

DISCUSSION

We conducted an exploratory investigation of a drumming intervention in a halfway house setting, with particular interest in qualitative experience to understand possible social and emotional effects that may suggest possible benefits for treatment and community reintegration. Quantitatively, we also assessed halfway house retention rate compared to a passive control group, and found that it was significantly higher in the drumming group. Qualitatively, our data analysis elicited three major themes. First, group drumming functions therapeutically as a method of coping with difficulty. Second, group drumming offers opportunity for connection through building relationship and experiencing communion in a setting where isolation is the norm. Third, group drumming provides an environment for personal growth, particularly toward re-humanization and self-empowerment.

Feasibility and Reception. Our results demonstrated the feasibility and positive reception of a group drumming intervention in a carceral setting, a secondary aim of this investigation. Beyond the logistical challenges and solutions – which may not applicable to other locations or clinical settings – our evaluation of feasibility included attendance levels, dropout rate, and how the drum group was received amongst participants. We highlight the high attendance rates, and the fact that the vast majority of absences were due to factors that lie outside of participant motivation. Further, only one individual quit the group (but still completed the post-interview and received compensation).

The reception was overwhelmingly positive from every single participant. Permeating each interview were compliments on the elements and facilitation of the program (“I really don't have a favorite part, man. The whole group all around was awesome…Real class act right there” [Participant 1, age 35]), desires to continue drumming beyond the intervention (“I could still go another eight weeks, do it again!” [Participant 8, age 54]), recommendations (I think that more guys should try it out and give it a try and really just go with it” [Participant 14, age 25]), and statements of gratitude and appreciation:

> And, and I really appreciate you guys, you know what I'm saying? Doing this for us, and and I, I'm pretty sure everybody feels the same way, or maybe better that what I feel, you know, everybody's different, but yeah, I I'm gonna I'm really gonna miss you guys, you know, I wish, you know, this is here to stay but unfortunately, you know, it's, we over, and I don't know, I just got to look for something else to do now. And, you want to shut it off? This, okay. Alright. And I don't know, you know, I just, we're just looking forward to every Sunday for you guys to come, you know, and we do this. (Participant 6, age 61)

And while this was certainly a self-selecting group of people, not everyone enjoyed it at first. Several participants named their initial apprehension, and many openly admitted that they just signed up for the financial compensation. Every single person who named a negative reaction went on to describe that this was only initially, and that it always shifted to a positive experience.

> I always thought it was for a different type of people, and I actually got something out of it. So. I appreciate it. (Participant 13, age 47)
>
> It grew on me, so I started to like this class, for sure. (Participant 9, age 20)

> I'm gonna be honest with you. In the beginning I didn't like this class, to be honest with you. But I got to start liking it a little bit, and I really missed, I really hate that we didn't have it yesterday. (Participant 10, age 50)

All of this can help explain the surprisingly high attendance rates. Further, only one individual dropped out of the drumming program. He still chose to complete the exit-interview, in which he shared that he actually enjoyed the group, and then explained his departure:

> You want to be honest about it? …Well, here we go. The time that we do the drum groups is the time I sneak down to go get my food. So I'm trying to like, damn. I'm playing with like, doing the drum, go and get the food… Cuz I don't eat the food here. I don't eat any of their food. They serve this crap here. I don't eat that… (Participant 7)

While there may be more left unsaid in this participant's statement, we include this to remind the reader of the structural and institutional factors that are always shaping the experiences and choices of those incarcerated. These factors must be addressed, and it is notably in spite of these factors that the drumming group was so successful and so well received.

Almost all feedback was essentially "more of what you're doing already." This included multiple requests to increase frequency of sessions per week, increase length of the program, and expand the program to have interventions inside other halfway houses, inside prisons, and outside in the community. The sum total of "negative" feedback included a single participant wishing for a different time of day and another participant who initially got headaches from the noise (and who, after the third week, began wearing headphones and had no further problems).

Finally, as mentioned in the results, several participants connected this to their prior love of music as a whole. This includes music playing a role of recreation as well as stress reduction in their lives, and how the drumming was a continuation of this. Clearly this intervention was accessible and relatable. In contrast, while other interventions may similarly facilitate coping, connection, and personal growth – such as writing groups, art groups, meditation, yoga – we wonder if these may not be quite as accessible and positively received, especially given this community of mostly low/no-income, often hypermasculine men of color with limited formal education.

Halfway House Retention. The quantitative finding of significantly lower frequency of escaping the halfway house in the drumming group suggests a beneficial effect of maintaining motivation to complete the incarceration sentence in the halfway house. Interestingly, related literature has shown that group drumming for at-risk youth increased school attendance (Faulkner et al., 2012), and the incorporation of group drumming in adult substance use treatment increased the program's attendance and retention rate (Blackett & Payne, 2005). We recall that this was specifically discussed by one of the participants, providing some insight into why this might be the case. This particular participant referenced a sense of accountability to the group; we might further extrapolate from the interviews that the stated experience of increased motivation and self-empowerment – and perhaps other stated benefits of coping and community –

facilitated a choice to remain in the halfway house. Regardless of their intention to stay in the program, maintained retention consequently means increased time of treatment and increased opportunity to find employment to stabilize community reintegration. Thus, this is an important finding with implications for clinical treatment.

Exploring Drumming for Coping. The utility of the drum group as a way of coping permeated every participant interview. The most common emotional experiences that the drumming helped participants work through were stress and anger, and the rhetoric of "getting it out" that several participants used invokes a process of turning stress and anger into expression via the drum. Drumming may be an ideal way to communicate these particular emotions nonverbally; literature suggests how drumming is best able to convey emotions like anger and fear (Behrens & Green, 1993; Bodner & Gilboa, 2006), and that techniques accessible to beginning drummers like increasing volume helps to convey tension and anger (Juslin, 1997, 2000; Krumhansl, 1996).

Either through this expression or entirely circumventing the process of expression, participants named a relief of the stress or anger. Whether this happened through distraction, a meditative process, or a release/escape, there was almost always an implied or explicit shift in emotions. This shift used language like "cool and calm," relaxed, and "peace of mind" – all of which map on to positive valence and low arousal. Not only are they feeling "better," they seem to be experiencing a decrease in the energetic intensity of the emotion. Such release of high arousal negative valence emotions (fear, anxiety, stress, anger) toward low arousal positive valence (relaxation, calm, comfort) is substantiated by drumming studies for refugees (Orth, 2005; Orth et al., 2004), those suffering substance use disorders (Winkelman, 2003), and combat veterans with trauma history (Bensimon et al., 2008; Burt, 1995). This literature matches our data in suggesting the efficacy of drumming in processing high arousal states – and perhaps high arousal psychopathology, such as post-traumatic stress disorder (PTSD).

While we did not collect information on mental health diagnoses for the participants of our study, it is well established that that individuals engaging in criminal activity often have a traumatic history (Carlson & Shafer, 2010; Dierkhising et al., 2013; Dutton & Hart, 1992; Elbogen et al., 2012; Weeks & Widom, 1998). Further, criminal psychology has focused heavily on the place of antisocial behaviors, attitudes, and thinking styles in those who commit crime (Andrews & Bonta, 2010; Wooditch, Tang, & Taxman, 2014), and it is well established that antisocial tendencies are correlated with life trauma (Bruce & Laporte, 2015; Fontana & Rosenheck, 2005; Semiz et al., 2007). The full interviews showed no dearth of lifelong trauma amongst the participants of the drumming group. However, other than one session after discussing lyrics to a song, our participants rarely shared their trauma in the group, and the interviews did not connect the drumming to healing or working through trauma. Bensimon et al. (2008) observed that drumming facilitated non-intimidating access to traumatic memories, and our own study certainly showed how drumming creates a safe communal space that would be necessary for such access, so we do not discount the possibility of such a connection in future work. Future research can more specifically ask about trauma and PTSD symptoms, and this can be more explicitly discussed in the group intervention.

Exploring Drumming for Connection. The drum group offered connection to the participants, both behaviorally through relationship and experientially through a sense of communion. These findings of experienced community and belonging are supported even in the relatively scarce literature of drum interventions. In a study by Winkelman (2003), drumming was used as an adjunct therapy for substance use disorder, where it was noted to alleviate a sense of isolation and create a sense of connectedness with others. In working with veterans generally and those with PTSD, Burt (1995) and Bensimon et al. (2008) saw that drumming increased a sense of belonging, connectedness, and intimacy. The importance of building connection for recovery amongst those with trauma is already well-established (Harvey, 1991; Herman, 2015; Van der Kolk, 1987, 2015). This is relevant and valuable given the aforementioned high rates of trauma in incarcerated communities.

Relatedly, it is important to highlight that this building of connection through drumming occurred in a setting where isolation was the norm, with over half of the participants discussing habits of staying to themselves. Beyond the isolative nature of trauma itself, this “loner” mentality is not uncommon for incarcerated adults generally; and, as reflected in our own results, such isolation is often an explicit method of coping and self-preservation (Harer, 1995; Lahm, 2009). And beyond the agency of the individuals, the prison system itself literally functions – by definition – to enforce isolation as a form of punishment, from limited visitation and contact with the outside world up to extended solitary confinement.

Such isolation is the most frequent concern of inmates, and it predicts maladjustment in a variety of forms: “misbehavior,” emotional disorders, self-harm, and suicide attempts, to name a few (Adams, 1992; Liebling, 1993; Sykes, 2007). These and other clinical effects of isolation and loneliness are well-established outside of the specificity of prison settings (Heinrich & Gullone, 2006), and which suggests that the drumming group may provide mental health benefits through the development of connection, beyond its discussed value as a coping mechanism.

Prisons have been heavily critiqued for stripping prisoners of the very support and connection that is necessary for successful growth and reintegration (Price, 2015), while numerous studies have demonstrated reduced recidivism and other beneficial effects of increased social connection in prisons (Bales & Mears, 2008; Cochran, 2014; Schenwar, 2014). Thus, the connection that the drum group elicits may further prove to be beneficial in the larger scheme of reducing imprisonment and facilitating incarcerated individuals’ successful reentry into their communities.

The current discourse on recidivism focuses heavily on antisocial behaviors, attitudes, and thinking styles (Andrews & Bonta, 2010; Wooditch et al., 2014). In the process of nurturing a sense of connection, our qualitative data suggests how drumming may actually counteract antisocial tendencies and facilitate improvement in these criminogenic factors. One study (Kokal et al., 2011) demonstrated that synchronized drumming between partners actually facilitated prosocial behavior. In this study, the drumming was associated with enhanced activity in the caudate, a brain region associated with reward-based learning, suggesting in internally rewarding experience that can engender such prosocial activity. In the long-term, this may facilitate a decrease in recidivism and should be further explored in a longitudinal study.

Exploring Drumming for Personal Growth through Re-humanization and Empowerment. Participants offered potent descriptions of how the drumming group facilitated reflection and growth. One key aspect of this was a process of re-humanization – of seeing themselves as a full human being, worthy of being heard and valued – that was in direct contrast to their usual experiences of incarceration. The dehumanizing experiences shared by our participants in prison settings is not unique; in fact, it is well recognized to be the norm, particularly in the United States (Alexander, 2012; Goffman, 1961; Hill, Cunningham, & Gentlemen, 2016; Human Rights Watch, 1991; Price, 2015). Beyond the confines of the prison, we note the high levels of trauma in this population – abuse, neglect, violence – as shared extensively in the participant interviews. Thus, the drumming group's capacity to counteract dehumanization and create conditions for growth has significant clinical implications for individuals with personal trauma and/or incarceration experiences. This might be accomplished in various ways, suggested by our results.

The first was illustrated by how the drum group also allowed participants to access a more complete narrative story of themselves that included identities beyond “felon” or “convict.” This occurred through how they were treated by the facilitator and researchers, as well as by how the drum group reopened connections to their interests in music and more positive life experiences. Given the known importance of self-narrative for psychological wellbeing (Adler, 2012; Baerger & McAdams, 1999; Pennebaker & Seagal, 1999), integrating a more complete self-narrative may be another avenue that a drum group can be beneficial. In accessing their own story in a more holistic way, multiple participants began to see different futures for themselves.

The second way drumming can resist dehumanization and facilitate growth, intimately related to redefining a narrative of self, is through the nurturing of self-empowerment. The drum group was often described as motivating and inspirational, and interviews were filled with stories newfound agency through both self-reflection and behavior— including one participant’s difficult choice not to escape despite a history of doing so. This increased agency and control through drumming has also been reflected in the work of others (Bensimon et al., 2008; Maschi et al., 2013; Slotoroff, 1994); even the increased prosocial behavior in the study by Kokal et al. (2011) was dependent on the ease of which the participant mastered the drummed rhythm, i.e. the sense of mastery gained over the task.

There has been significant research on the benefits of self-empowerment for incarcerated individuals. In a study of a maximum-security prison, Hill et al. (2016) highlights the ability to "express a sense of agency" as important to counteract "feelings of oppression and valuation," i.e. the dehumanization of the institution. Maruna (2001) has extensively researched how those who were incarcerated go on to reform and rebuild their lives, particularly through identifying differences between those who continue to partake in crime and those who do not. While he found no difference in such factors as education, psychopathology, and life histories of trauma and abuse, what he did find was a difference in whether or not they felt they had agency over their lives. Those who managed to move out of a life of crime felt the locus of control resided within them, that they were the agents of their own futures.

Limitations. While this group drumming investigation offers novel insight to the possible effects of drumming in an incarcerated population, it too has its limitations. First, as they opted into the intervention (at risk of randomization to the Treatment as Usual group), there is the possibility of selection bias; it is possible that such an intervention may not be received as positively amongst individuals not interested in drumming to begin with.

As a qualitative study dependent on interviews, we are limited in our analysis to what participants choose to share with us. Given their long-term experiences of navigating institutions that rarely have their best interests in mind, it is possible that they felt pressure to exaggerate or share only the positive effects of the group. That said, we aimed to elicit and analyze concrete examples to limit reliance on generalized statements.

As with all qualitative research, our coding and thematic analysis is dependent on the particular subjectivities and biases of the researchers. Consistent with a constructivist grounded theory (Charmaz, 1995, 2000; Mills, Bonner, & Francis, 2006), we recognize the relationship between researchers and participants, and the ensuing co-creation of meaning from the collected data. We chose to rely heavily on participant quotes to stay close to the participant experience, and the use of multiple coders with regular discussion of discrepancies helped us to check biases and ensure truthful representation of our data.

The small sample size of our intervention limited the quantitative data we could collect and analyze. Using these qualitative results to generate hypotheses, it would be important for future quantitative research to expand on our work in a number of ways. In exploring the dimensions of coping, it would be important to use larger sample sizes to evaluate the effects of such interventions on PTSD symptomatology. In terms of connection, scales to evaluate dimensions like perceived social support could help disentangle the effects of relationship versus the experience of communion. Regarding personal growth and empowerment, quantitative results could better explore changes in self-empowerment or sense of agency as correlated to tangible behavioral change. All of these effects could be correlated to recidivism in larger longitudinal studies to inform the importance and implementation of these interventions.

Finally, we recognize that our research – which focuses on individual experiences of coping, connection, and agency – may inadvertently imply that the onus is entirely on individuals to improve their own lives. While the "big four" causes of recidivism focus on individual attitudes and behaviors, the larger list of the "central eight" highlight larger interpersonal and systemic factors such as family and employment. Discourse focusing on the role of individuals often omits the myriad ways society has failed such individuals. This is particularly true in the United States, where the astronomical (and ever-increasing) numbers of those in prison – i.e. mass incarceration – points to a much larger societal failing (Alexander, 2012; Gottschalk, 2006; Kirchhoff, 2010; Manza & Uggen, 2004; Thompson, 2012). Inextricable from the issue of mass incarceration is the issue of who it affects: people of color (especially black, Latinx, and indigenous persons) are far more likely to end up in the prison system, which is a result of institutional racism at multiple levels of the prison industrial complex (Alexander, 2012; Brewer & Heitzeg, 2008; Davis, 2011; Gilmore, 2007; Gottschalk, 2006; Pager, 2008; Rios, 2011). And for all of this enforced trauma on particular populations coinciding with a rise in corporate involvement (e.g. private prisons), there has been little to show for it, including no reduction in crime rate (Stemen, 2017; Wacquant, 2009). The demographics of our own study – and the copious examples of dehumanization expressed by our participants – emphasize the relevance of this work. We hope to underscore the importance of addressing institutional and systemic factors necessary in the healing and thriving of incarcerated individuals, and by extension the healing and thriving of all people. Nevertheless, this research shows an important access point, and we invite the perspective that the availability and implementation of interventions like the drumming group for therapeutic benefit may indeed be a part of systemic change.

CONVERGENCE AND CONCLUSIONS

This two-pronged investigation demonstrated the positive social and emotional effects of drumming from neuroscientific, behavioral, and phenomenological perspectives. The convergence of the two studies elucidates important new insights and frameworks for future research and application.

TPJ in Emotion Regulation, Self, and Agency. We observed that higher intensity drumming was associated with image stimuli characterized by higher arousal and lower valence qualities, as well as with greater TPJ activation. This suggests expression and processing of difficult emotions via drumming, which was well correlated with our qualitative findings. One of the key themes was coping, most commonly in a discussion of stress and anger, both of which would map to high arousal and low valence. Such emotional processing may be described through the statements within this coping theme that suggest the importance of expression itself to relieve stress ("beat my… troubles… my stress," or "to let something out"). Thus, the suggestion from the fNIRS investigation and the literature that drumming may prove more useful for arousal-related psychopathology may be being demonstrated in our qualitative data. That said, we did not collect information on mental health diagnoses for the participants of our study, and future research in larger settings may be able to better report and correlate this.

Relatedly, The TPJ is also known to be involved in functions of reappraisal (Buhle et al., 2014; Grecucci et al., 2013; McRae et al., 2010) or the reinterpretation of emotional stimuli in new ways that support emotion regulation. This may be fundamental to the descriptions of emotion regulation in the qualitative findings, particularly in the process of coping with difficulty. Further, it is possible that this reappraisal creates the opportunity for self-reflection and growth, another key theme of the participant interviews.

Much of the personal growth was related to a sense of self and agency. Literature has amply discussed the role of TPJ in self-other representation and differentiation (Blanke et al., 2005; Plaze et al., 2015). This sense of self may be a crucial first step in the capacity to grow, perhaps related to the re-humanization experiences that participants described. In developing a coherent theory of the TPJ vis-à-vis self-other differentiation, Eddy (2016) has reviewed the importance of the TPJ for multisensory integration to create this sense of self, as well as the role of TPJ in eliciting a sense of agency. Thus, this TPJ activation may be central to strengthening the story and the agency of self in group drummers.

In fact, this activation may even provide a counter to the various previously discussed abnormalities in the TPJ (especially rSTG) that are associated with criminal psychopathy, histories of abuse, and PTSD (De Bellis, Keshavan, Frustaci, et al., 2002; Müller et al., 2008; Tomoda et al., 2011). TPJ may thus be the mechanism through which drumming could facilitate pro-social behaviors and improve recidivism.

Connection in Drumming, TPJ, and Neural Synchrony. At the convergence of our neural findings and the experienced sense of connection, we recall that several participants spoke of sticking to themselves except in the drum group, which was "different." This suggests that the drumming offered a distinct and more accessible mechanism for connecting than talking or other daily interaction. Neurally, we might correlate this to the increased activation of the TPJ in drumming versus talking. Perhaps through this different circuitry, normal inhibitions to social-emotional connection were able to be overcome. This might prove especially clinically relevant in settings such as prisons and halfway houses such as ours, which are associated with communities with lower levels of education and consequently more limited capacity for verbal expression. Our neural findings suggest that such verbal expression may not actually be as important as we tend to assume for therapeutic benefit.

In a further convergence of "connection" and neural findings, we again return primary significance of the TPJ. Its increased activity when listening to increased intensity of drumming in a social setting may suggest activation of mentalizing, intention-attribution, and empathic functions (associated with TPJ) in these settings. This may in turn facilitate or be a neural correlate of the increased sense of connection that was experienced in the drum group. Indeed, participants specifically spoke of the drum group as a place where they learned more about each other and would "share things" with each other; the reception of the other participants' drumming may be an example of such sharing, or something that facilitated later verbal sharing and connection after having engaged these functions of theory of mind and empathy.

The observed affective spectrum of connection culminated in some participants' descriptions of a sense of unity, even "spiritual" synchronicity. The participants' very language of being "in sync" calls to mind the TPJ to TPJ neural synchrony. It is possible that these descriptions of communion his may represent a phenomenological correlate to the quantitative finding of increased cross-brain coherence during interactive drumming in our fNIRS results. This is further substantiated by the fact that this coherence happened in a more interactive "dialogue" condition. This dialogue condition is certainly not equivalent to the moment-to-moment interplay of live communication, but it represents a step between the monologue condition and the group drumming setting. It is possible that we would see even stronger coherence in such a live group drumming context.

Conclusions and Future Directions. This study investigated a breadth of social and emotional effects of drumming. Neuroscientifically, we elicited the particular contribution of drumming to emotional communication that is associated with activity in the right TPJ. The observed sensitivity of the STG and SMG within the right TPJ during listening, a canonical social and emotion processing center, holds implications for social-emotional psychopathology. Future research on nonverbal auditory communication in clinical contexts, ranging from autism to PTSD, is informed by these findings. Further, our direct application of a drumming intervention for an incarcerated population highlights the possible success of motivating individuals to complete treatment and reintegration, and it suggests the therapeutic benefits of group drumming through coping with stresses and difficulties, nurturing connection through relationship and communion, and cultivating personal growth through re-humanization and self-empowerment.

Future directions at the convergence of these studies are fascinating and infinite. For my own extension of these investigations, I am particularly inspired by the burgeoning field of neurophenomenology, which sits at the intersection neuroscience and lived experience. Here, I could combine the fNIRS with the qualitative data to map our proposed correlations. With say twenty subjects in intervention and control groups, we may identify differences in neural (especially TPJ) activation before and after the intervention, including possible changes in neural synchrony between partners before and after engaging in the intervention together. Participants could participate in an fNIRS experimental paradigm similar to our current model both pre- and post-intervention, and neural data collection could be temporally combined with qualitative data collection about the immediate experience of drumming from run to run of the experiment in order to determine how and which experiences are most correlated to particular neural activity and synchrony.

On a broader scale, future related research would benefit from larger interventions, perhaps multi-site, that can collect and analyze quantitative data through pre-post change scores in self-report questionnaires (e.g. to correlate phenomenology with measures of quantified perceived social support, agency, empathy, and PTSD symptoms). Ideally, these would be compared to both a passive and an active control group, such as a writing or arts intervention. Analyzed longitudinally, recidivism could be tracked, either ensuring that these short-term effects are reflected in longer term individual and societal benefits, or identifying societal barriers where beneficial effects are being inhibited.

Such larger, longitudinal studies with self-report quantitative data, combined with findings from neurophenomenological paradigms, have immense potential for informing more targeted, effective, and clinically relevant group drumming interventions for therapeutic benefit beyond our current models— for individuals, communities, and society at large.

SUPPLEMENTARY MATERIAL

Table S1. Median MNI coordinates and Anatomical Regions of Channels

Channel Number	MNI Coordinates X	Y	Z	Anatomical Region	BA	Probability
1	64	-23	50	Supramarginal Gyrus, part of Wernicke's Area	40	0.72
				Primary Somatosensory Cortex	1	0.24
				Primary Somatosensory Cortex	2	0.04
2	68	-35	40	Supramarginal Gyrus, part of Wernicke's Area	40	0.94
				Angular Gyrus, part of Wernicke's Area	39	0.06
3	67	-10	37	Primary Somatosensory Cortex	1	0.48
				Primary Somatosensory Cortex	2	0.43
				Primary Somatosensory Cortex	3	0.05
				Supramarginal Gyrus, part of Wernicke's Area	40	0.04
4	22	51	45	Dorsolateral Prefrontal Cortex	9	0.99
				Dorsolateral Prefrontal Cortex	46	0.01
5	54	-75	21	V3	19	0.6
				Angular Gyrus, part of Wernicke's Area	39	0.4
6	68	-50	23	Angular Gyrus, part of Wernicke's Area	39	0.59
				Superior Temporal Gyrus	22	0.37
				Supramarginal Gyrus, part of Wernicke's Area	40	0.03
				Middle Temporal Gyrus	21	0
				Fusiform Gyrus	37	0
7	70	-25	27	Supramarginal Gyrus, part of Wernicke's Area	40	0.53
				Primary Somatosensory Cortex	2	0.27
				Retrosubicular Area	48	0.18
				Superior Temporal Gyrus	22	0.02
8	67	1	23	Subcentral Area	43	0.83
				Primary Somatosensory Cortex	2	0.1
				Superior Temporal Gyrus	22	0.07
				Retrosubicular Area	48	0.01

				Primary Somatosensory Cortex	1	0
9	59	29	19	Pars Opercularis, part of Broca's Area	44	0.49
				Pre-Motor and Supplementary Motor Cortex	6	0.4
				Pars Triangularis, part of Broca's Area	45	0.11
10	40	52	29	Pars Triangularis, part of Broca's Area	45	0.63
				Dorsolateral Prefrontal Cortex	46	0.37
11	62	-63	3	V3	19	0.4
				Angular Gyrus, part of Wernicke's Area	39	0.31
				Fusiform Gyrus	37	0.29
12	71	-39	13	Superior Temporal Gyrus	22	0.74
				Middle Temporal Gyrus	21	0.24
				Fusiform Gyrus	37	0.02
				Retrosubicular Area	48	0
13	70	-12	14	Superior Temporal Gyrus	22	0.58
				Primary Somatosensory Cortex	2	0.31
				Subcentral Area	43	0.06
				Supramarginal Gyrus, part of Wernicke's Area	40	0.03
				Retrosubicular Area	48	0.02
14	63	12	6	Retrosubicular Area	48	0.54
				Superior Temporal Gyrus	22	0.19
				Pre-Motor and Supplementary Motor Cortex	6	0.16
				Subcentral Area	43	0.08
				Middle Temporal Gyrus	21	0.03
15	49	49	13	Pars Triangularis, part of Broca's Area	45	0.89
				Dorsolateral Prefrontal Cortex	46	0.11
16	24	65	26	Dorsolateral Prefrontal Cortex	46	0.63
				Frontopolar Area	10	0.37
				Dorsolateral Prefrontal Cortex	9	0.01
17	68	-51	-5	Fusiform Gyrus	37	0.94
				Middle Temporal Gyrus	21	0.06
18	73	-27	-3	Superior Temporal Gyrus	22	0.73

				Middle Temporal Gyrus	21	0.27
19	69	-5	-7	Middle Temporal Gyrus	21	0.54
				Superior Temporal Gyrus	22	0.44
				Retrosubicular Area	48	0.03
20	56	39	-1	Pars Triangularis, part of Broca's Area	45	0.87
				Temporopolar Area	38	0.1
				Retrosubicular Area	48	0.04
21	36	64	11	Dorsolateral Prefrontal Cortex	46	0.55
				Frontopolar Area	10	0.45
22	-60	-19	50	Primary Somatosensory Cortex	2	0.56
				Supramarginal Gyrus, part of Wernicke's Area	40	0.26
				Primary Somatosensory Cortex	1	0.17
				Primary Somatosensory Cortex	3	0.01
23	-19	51	44	Dorsolateral Prefrontal Cortex	9	1
24	-63	-7	40	Subcentral Area	43	0.62
				Primary Somatosensory Cortex	2	0.2
				Primary Somatosensory Cortex	1	0.09
				Retrosubicular Area	48	0.09
25	-65	-33	42	Retrosubicular Area	48	0.35
				Superior Temporal Gyrus	22	0.32
				Supramarginal Gyrus, part of Wernicke's Area	40	0.26
				Primary Somatosensory Cortex	2	0.06
				Primary and Auditory Association Cortex	42	0.01
26	-38	51	28	Dorsolateral Prefrontal Cortex	46	0.86
				Pars Triangularis, part of Broca's Area	45	0.14
27	-56	29	19	Pars Triangularis, part of Broca's Area	45	0.92
				Pars Opercularis, part of Broca's Area	44	0.08
28	-65	3	24	Subcentral Area	43	0.46
				Pre-Motor and Supplementary Motor Cortex	6	0.29
				Retrosubicular Area	48	0.18
				Superior Temporal Gyrus	22	0.07

29	-68	-21	31	Superior Temporal Gyrus	22	0.68
				Primary Somatosensory Cortex	2	0.17
				Retrosubicular Area	48	0.07
				Primary and Auditory Association Cortex	42	0.06
				Middle Temporal Gyrus	21	0.02
30	-67	-47	29	Middle Temporal Gyrus	21	0.42
				Superior Temporal Gyrus	22	0.38
				Fusiform Gyrus	37	0.2
31	-57	-69	30	V3	19	0.47
				Fusiform Gyrus	37	0.45
				Angular Gyrus, part of Wernicke's Area	39	0.09
32	-21	64	24	Frontopolar Area	10	0.98
				Dorsolateral Prefrontal Cortex	46	0.02
33	-46	49	12	Dorsolateral Prefrontal Cortex	46	0.78
				Pars Triangularis, part of Broca's Area	45	0.2
				Frontopolar Area	10	0.02
34	-60	16	9	Retrosubicular Area	48	0.45
				Temporopolar Area	38	0.22
				Pre-Motor and Supplementary Motor Cortex	6	0.12
				Pars Opercularis, part of Broca's Area	44	0.11
				Pars Triangularis, part of Broca's Area	45	0.1
35	-68	-9	19	Superior Temporal Gyrus	22	0.79
				Middle Temporal Gyrus	21	0.11
				Retrosubicular Area	48	0.1
				Subcentral Area	43	0
36	-69	-36	17	Superior Temporal Gyrus	22	0.56
				Middle Temporal Gyrus	21	0.39
				Inferior Temporal Gyrus	20	0.05
37	-64	-57	10	Fusiform Gyrus	37	0.92
				Middle Temporal Gyrus	21	0.08
38	-33	64	10	Frontopolar Area	10	0.9

				Orbitofrontal Area	11	0.09
				Dorsolateral Prefrontal Cortex	46	0.01
39	-53	40	0	Pars Triangularis, part of Broca's Area	45	0.5
				Dorsolateral Prefrontal Cortex	46	0.44
				Inferior prefrontal Gyrus	47	0.06
40	-65	-1	-6	Middle Temporal Gyrus	21	0.98
				Temporopolar Area	38	0.02
41	-70	-23	1	Middle Temporal Gyrus	21	0.95
				Superior Temporal Gyrus	22	0.03
				Inferior Temporal Gyrus	20	0.03
42	-68	-46	1	Inferior Temporal Gyrus	20	0.53
				Fusiform Gyrus	37	0.24
				Middle Temporal Gyrus	21	0.23

Table S2. Neuroimaging Results of all Significant Positive Comparisons

Contrast	Locus	MNI Coordinates			Effect	*p*	Prob	BA	Anatomical Region
		X	*Y*	*Z*					
Drum: Strike-by-Strike	1	64	-52	24	-3.49	0.00078	0.49	40	Supramarginal Gyrus
(Drum>Listen)							0.35	22	Superior Temporal Gyrus
							0.16	39	Angular Gyrus
	2	64	-46	6	-3.84	0.00031	0.56	22	Superior Temporal Gyrus
							0.40	21	Middle Temporal Gyrus
	3	60	-16	42	3.58	0.00061	0.43	22	Pre-/Supplementary Motor Cort
							0.18	1	Primary Somatosensory Cortex
							0.17	3	Primary Somatosensory Cortex
							0.12	2	Primary Somatosensory Cortex
	4	-50	-6	36	3.11	0.00211	1.00	22	Pre-/Supplementary Motor Cort
Drumming > Talking	1	62	-36	28	5.32	<0.00001	0.41	40	Supramarginal Gyrus
							0.25	22	Superior Temporal Gyrus
							0.21	2	Primary Somatosensory Cortex
							0.13	48	Retrosubicular Area
	2	-66	-30	30	3.78	0.0003	0.42	2	Primary Somatosensory Cortex
							0.20	40	Supramarginal Gyrus
							0.15	48	Retrosubicular Area
							0.15	22	Superior Temporal Gyrus

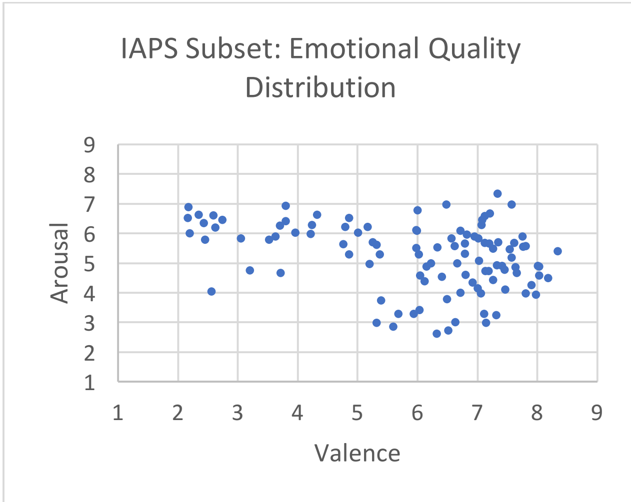


Figure S1: Distribution of this investigation's subset of IAPS images by valence and arousal.

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Communication of emotion via drumming: dual-brain imaging with functional near-infrared spectroscopy

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Abstract

Nonverbal communication of emotion is essential to human interaction and relevant to many clinical applications, yet it is an understudied topic in social neuroscience. Drumming is an ancient nonverbal communication modality for expression of emotion that has not been previously investigated in this context. We investigate the neural response to live, natural communication of emotion via drumming using a novel dual-brain neuroimaging paradigm. Hemodynamic signals were acquired using whole-head functional near-infrared spectroscopy (fNIRS). Dyads of 36 subjects participated in two conditions, drumming and talking, alternating between 'sending' (drumming or talking to partner) and 'receiving' (listening to partner) in response to emotionally salient images from the International Affective Picture System. Increased frequency and amplitude of drum strikes was behaviorally correlated with higher arousal and lower valence measures and neurally correlated with temporoparietal junction (TPJ) activation in the listener. Contrast comparisons of drumming greater than talking also revealed neural activity in right TPJ. Together, findings suggest that emotional content communicated by drumming engages right TPJ mechanisms in an emotionally and behaviorally sensitive fashion. Drumming may provide novel, effective clinical approaches for treating social–emotional psychopathology.

Key words: fNIRS; drumming; communication; emotion; arousal; valence

Introduction

Research on the communication of emotion has focused primarily on the neural mechanisms of communicating via speech, despite the fact that emotion is also communicated through nonverbal modalities ranging from music to body language. As these modalities are often used instead of or in addition to speech, we hypothesize that they offer something unique or supplemental that merits investigation and may have unique clinical application. Further, the communication of emotion is a bidirectional process, which includes both sensitivity to the emotional cues of others as well as the expression of internal emotional states to others. Generally, emotion research has focused on the unidirectional process of perception or induction (i.e. the brain's reactivity to emotional stimuli), in large part due to the limitation of conventional neuroimaging modalities to single subjects. This study utilized a simultaneous, dual-brain neuroimaging paradigm to study bidirectional communication of emotion, including sending and receiving emotional content. In particular, we investigated the neural correlates of communicating emotion via drumming and listening, as compared to talking and listening.

Drumming is an ancient nonverbal form of communication that has been used across the world throughout history, with some of the earliest drums dating back to 5500–2350 BCE in China (Liu, 2005). They have typically played a communicative

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role in social settings, which may point to their evolutionary origin (Randall, 2001; Remedios *et al.*, 2009). For example, slit drums and slit gongs—used from the Amazon to Nigeria to Indonesia—often use particular tonal patterns to convey messages over distance (Stern, 1957). Similarly, the renowned 'talking drums' of West Africa convey information with stereotyped stock phrases that mimic the sounds and patterns of speech (Stern, 1957; Carrington, 1971; Arhine, 2009; Oluga and Babalola, 2012). These drums have been used to communicate messages over thousands of kilometers by relaying from village to village (Gleick, 2011). However, these drums are also used in other communal settings, including dancing, rituals, story-telling and other ceremonies (Carrington, 1971; Ong, 1977), suggesting that they hold not only semantic information but also emotional information.

Drums are typically used in social or ceremonial settings, without holding semantic information and without intention to mimic speech. Such drumming serves various functions of emotional communication, such as to instill motivation or fear (e.g. during war), synchronize group activity (e.g. agricultural work or marching) or build social cohesion (recreational and ceremonial drum circles). For example, Wolf (2000) explores how drums are used among South Asian Shi'i Muslims in the mourning process that commemorates the killing of a political and spiritual leader at the Battle of Karbala in 680 CE. He points to how various qualities of drumming may facilitate the listener's emotional relationship with the event (e.g. slow tempo for sadness, loud drum strikes for the intensity of grief).

The use of drums in situations where verbal communication is also used suggests that drumming provides added value to verbal communication, possibly deepening the emotional experience. In this study, we aim to understand the putative neural mechanisms that underlie bidirectional communication of emotion via drums.

Functional near-infrared spectroscopy (fNIRS) uses signals based on hemodynamic responses, similar to functional magnetic resonance imaging (fMRI), and with distinct features that are beneficial for the study of communication. For example, the signal detectors are head-mounted (i.e. non-invasive caps), participants can be seated directly across from each other while being simultaneously recorded, the system is virtually silent and data acquisition is tolerant of limited head motion (Eggebrecht *et al.*, 2014). These features facilitate a more ecologically valid neuroscience of dual communicating brains.

The fNIRS hemodynamic signals are based on differential absorption of light at wavelengths sensitive to concentrations of oxygenated and deoxygenated hemoglobin (deoxyHb) in the blood. As with fMRI, observed variation in blood oxygenation serves as a proxy for neural activity (Kato, 2004; Ferrari and Quaresima, 2012; Scholkmann *et al.*, 2013; Gagnon *et al.*, 2014). Although it is well documented that blood oxygen level–dependent (BOLD) signals acquired by fMRI and hemodynamic signals acquired by fNIRS are highly correlated (Strangman *et al.*, 2002; Sato *et al.*, 2013), the acquired signals are not identical. The fNIRS system acquires both oxygenated hemoglobin and deoxyHb. The deoxyHb signal most closely resembles the fMRI signal (Sato *et al.*, 2013; Zhang *et al.*, 2016) and is thus reported here. The fNIRS signals originate from larger volumes than fMRI signals, limiting spatial resolution (Eggebrecht *et al.*, 2012). However, the fNIRS signal is acquired at a higher temporal resolution than the fMRI signal (20–30 ms *vs* 1.0–1.5 s), which benefits dynamic studies of functional connectivity (Xu Cui *et al.*, 2011). Due to the mechanics of emitting infrared light, the sensitivity of fNIRS is limited to cortical structures within 2–3 cm from the skull surface. Although fNIRS is well established (particularly in child research where fMRI approaches remain difficult or contraindicated), recent adaptations of fNIRS for hyperscanning enable significant advances in the neuroimaging of neural events that underlie interactive and social functions in adults (Funane *et al.*, 2011; Dommer *et al.*, 2012; Holper *et al.*, 2012; Cheng *et al.*, 2015; Jiang Jiang *et al.*, 2015; Osaka *et al.*, 2015; Vanutelli *et al.*, 2015; Hirsch *et al.*, 2017; Piva *et al.*, 2017).

Study Overview. We investigated the neural response to the communication of emotional content of visual stimuli via drumming in a face-to-face paradigm, eliciting the contribution of drumming to auditory emotion communication. We chose drumming as the communication modality given its accessibility to a first-time user, thus enhancing the potential for clinical application. In our experimental paradigm, pairs of subjects (dyads) were presented with images from the International Affective Picture System (IAPS; Lang *et al.*, 2008), which served as the topic for communication via either drumming or talking. We identified the relationship between drumming behavior and arousal or valence of the IAPS images. We then evaluated the neural sensitivity to drum behavior in both drummer and listener in order to characterize the communication of emotion. Finally, we compared the neural correlates of drumming and talking to evaluate the possible unique neural contribution of drumming over talking as a communication modality.

The IAPS images employ a two-dimensional emotion framework that distinguishes the emotional qualities of arousal and valence, as most classically represented in Russell's circumplex model (1980). Arousal is a measure of the intensity or activating capacity of an emotion, ranging from low (calm) to high (excited); low arousal emotions may include sadness or contentedness, while high arousal emotions may include excitement or anger. Valence is a measure of the pleasure quality of the emotion, ranging from negative (unpleasant) to positive (pleasant); negative valence emotions may include sadness or anger, while positive valence emotions may include contentedness or excitement. Each of the IAPS images is indexed by valence and arousal ratings, allowing us to regress neural activity against these emotional qualities (Lang *et al.*, 2008).

The hypothesis for this investigation was 2-fold. First, we hypothesized that strike-by-strike drum measures that communicate expressions of valence and arousal would elicit activity in brain systems associated with social and emotional functions, i.e. the right temporoparietal junction (TPJ). Second, we hypothesized that drumming in response to emotional stimuli would elicit neural activity that was greater than talking in the TPJ.

Methods

Participants

Thirty-six (36) healthy adults [18 pairs of subjects; mean age, 23.8 ± 3.2; 86% right handed (Oldfield, 1971)] participated in the study. Sample size is based on power analyses of similar prior two-person experiments showing that a power of 0.8 is achieved by an n of 31 (Hirsch *et al.*, 2017). All participants provided written informed consent in accordance with guidelines approved by the Yale University Human Investigation Committee (HIC #1501015178) and were reimbursed for participation. Dyads were assigned in order of recruitment; participants were not stratified further by affiliation or dyad gender mix.

Table 1. Demographic Information

Category	Subcategory	Total/Avg
N		36
Age		23.8 ± 3.2
Gender		
	Male	17
	Female	19
	Other	0
Race		
	Asian/Pacific Islander	17
	Black/African American	2
	Latin/Hispanic	0
	Middle East/N African	1
	Native/indigenous	0
	White/European	10
	Biracial/multiracial	7
	Other	2
Dyad gender mix		
	Male/male	5
	Male/female	8
	Female/female	5
Handedness		
	Right	31
	Left	5
Music expertise*		3.14 ± 1.22
Drum expertise*		1.64 ± 0.93
Partner familiarity*		1.53 ± 1.23

*Based on Likert Scale responses ranging from 1 to 5 for musical expertise (never played to plays professionally), drumming expertise (never played to plays professionally) and partner familiarity (never seen or spoken to best friends).

Participants rated their familiarity with their partner, their general musical expertise and their drumming expertise (descriptive statistics in Table 1). To facilitate drumming as a method of communication for participants regardless of previous experience, a brief interactive video tutorial was shown to all participants to acquaint them with various ways of striking the drum using both hands.

Table 1 includes demographic information for subjects and dyads, as well as participant characteristics regarding musical expertise, drum expertise and familiarity with experiment partner.

Experimental paradigm

Dyads were positioned face to face across a table 140 cm from each other (Figure 1). Pseudo-randomized image stimuli presented on each trial were selected from a subset of the IAPS (Lang *et al.*, 2008). These images were presented to both participants via a monitor on each side of the table that did not obstruct view of their partner. In each trial, one subject responded to the image stimulus by drumming or talking while the other listened.

In the drumming condition, participants were encouraged to respond to the image however they felt appropriate, including a direct response to the emotional content of the image, drumming as if they were acting within the image (e.g. with punches or strokes), or drumming as if creating the soundtrack to the image. In the talking condition, participants were encouraged to speak about what they see, their experience with the elements of the image, their opinion about the image or elements within it or what came to mind in response to the image.

The images changed and roles alternated between 'sending' (drumming or speaking) and 'receiving' (listening to partner) every 15 s for 3 min (Figure 2). For example, as illustrated in Figure 2 Event 1, after Subject 1 had spoken about the space shuttle liftoff for 15 s while Subject 2 listened, an image of flowers (Figure 2, Event 2) replaced the space shuttle image on both subjects' screens, cuing Subject 2 to speak about this new image while Subject 1 listened. This 3-min run of alternating 'sending' and 'receiving' every 15 s thus totals 12 epochs. This was then repeated for a total of two runs of drumming and two runs of talking for each pair of subjects.

For each dyad, the following conditions were pseudo-randomized: order of experiment runs (i.e. dialogue runs first or drumming runs first), order of subjects responding within runs and order of subjects responding across runs. The order of presentation of the series of 96 images for each experiment was also randomized.

Image stimuli

The stimuli used for each experiment were a set of 96 images selected from the IAPS (Lang *et al.*, 2008). These images have established ratings for arousal (low to high) and valence (negative to positive) on a 1–9 Likert scale. Examples are given in Figure 3, and a scatterplot depicting the valence and arousal distributions of our image subset is included in Figure S1 (Supplementary Material). The library numbers of these images and their relevant statistics can be found in the appendix.

Quantified drumming response

The electronic drums utilized for this study use a Musical Instrument Digital Interface (MIDI) protocol to record quantity and force of drum strikes. For each run, we collected strike-by-strike information, including the average force of drum strikes, the total number of drum strikes and the product of these two values (providing a combined objective quantification of drumming response). This quantified drumming response was then correlated with the established arousal and valence ratings for image stimuli, serving as a behavioral measure of responses to IAPS images. Strike-by-strike measures were taken as the 'sending' variable.

Signal acquisition and processing

NIRS signal acquisition, optode localization and signal processing including global mean removal used here are similar to standard methods described previously for the deoxyHb signal (Noah *et al.*, 2015; Zhang *et al.*, 2016; Dravida *et al.*, 2017; Hirsch *et al.*, 2017; Noah *et al.*, 2017; Zhang *et al.*, 2017). Hemodynamic signals were acquired using a 64-fiber (84-channel) continuous-wave fNIRS system (Shimadzu LABNIRS, Kyoto, Japan). The cap and optode layout of the system provided extended head coverage for both participants achieved by distribution of 42 3-cm channels over both hemispheres of the scalp (Figure 4). Anatomical locations of optodes in relation to standard head landmarks were determined for each participant using a Patriot 3D Digitizer (Polhemus, Colchester, VT) (Okamoto and Dan, 2005; Singh *et al.*, 2005; Eggebrecht *et al.*, 2012; Ferradal *et al.*, 2014). The Montreal Neurological Institute (MNI) coordinates (Mazziotta *et al.*, 2001) for each channel were obtained using NIRS-SPM software (Ye *et al.*, 2009), and the corresponding

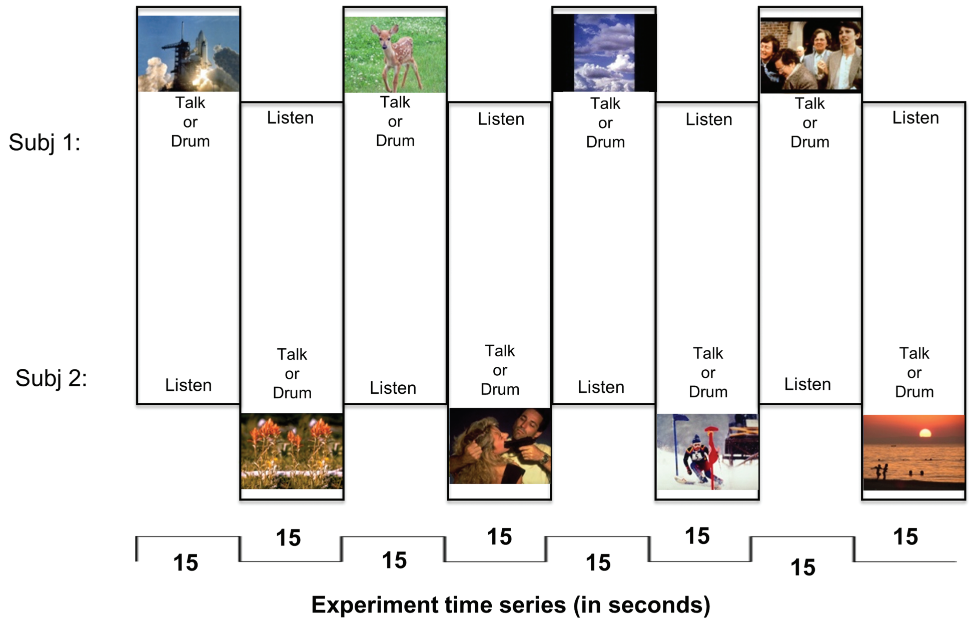

Fig. 1. Experimental paradigm. Each run is 3 min, 12 epochs (8 epochs shown here). Subjects alternate 'sending' (speaking or drumming) and 'receiving' when triggered by image change. Each image was selected from the IAPS library with established arousal and valence ratings.

Fig. 2. Experimental set-up for two interacting partners in the drumming condition. The talking communication condition was identical, but without the drum apparatus.

anatomical locations of each channel were determined by the provided atlas (Rorden and Brett, 2000). Table S1 (Supplementary Material) lists the median MNI coordinates and anatomical regions with probability estimates for each of the channels shown in Figure 4.

We applied pre-coloring in our experiment through high-pass filtering. Pre-whitening was not applied to our data. This decision was guided by a previous report showing a detrimental effect on neural responses during a finger-thumb-tapping task (Ye *et al.*, 2009). Baseline drift was modeled based on the time series and removed using wavelet detrending provided in NIRS-SPM. Global components resulting from systemic effects such as blood pressure (Tachtsidis and Scholkmann, 2016) were removed using a principal component analysis spatial filter (Zhang *et al.*, 2016) prior to general linear model (GLM) analysis. Comparisons between conditions were based on the GLM (Penny *et al.*, 2011). Event epochs were convolved with a standard hemodynamic response function modeled to the contrast between 'sending' (drumming or talking) and 'receiving' (listening), providing individual beta values of the difference for each participant across conditions. Group results were rendered on a standardized MNI brain template.

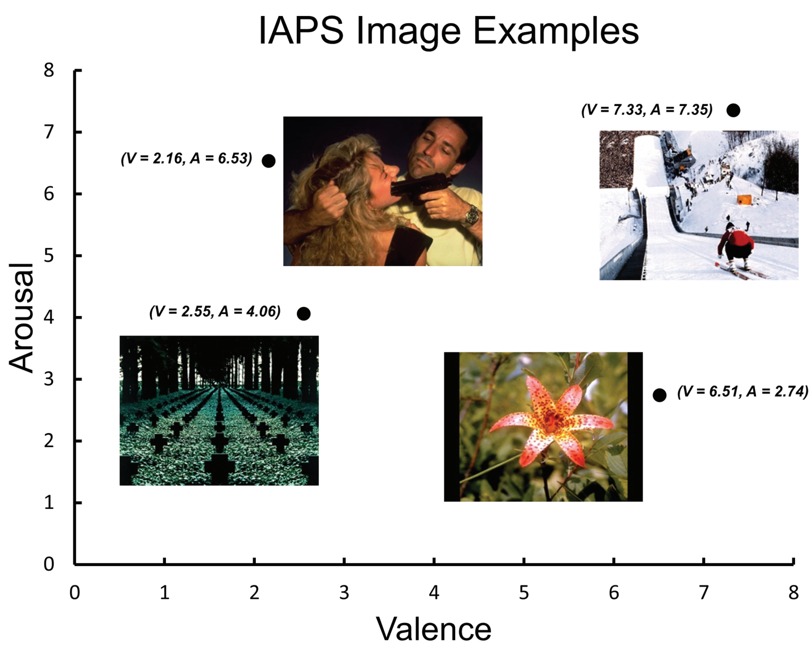

Fig. 3. Examples of IAPS images with low/high arousal (A) and negative/positive valence (V). The figure illustrates the arousal/valence index system for emotional qualities of each image.

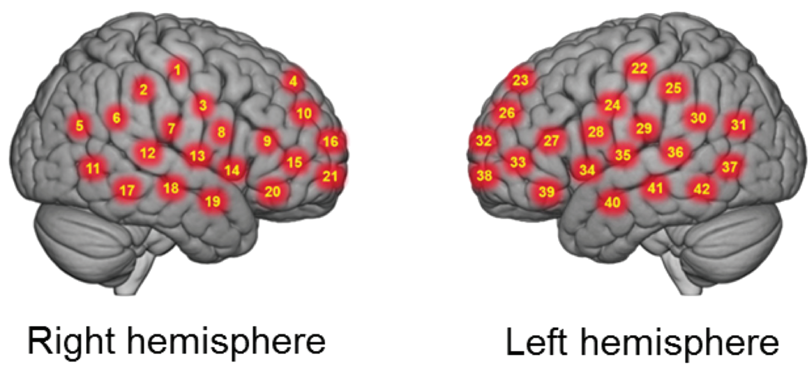

Fig. 4. Right and left hemispheres of a single-rendered brain illustrate average locations (red circles) for channel centroids. See Table S1 (Supplementary Material) for average MNI coordinates and anatomical locations.

Results

Drumming related to arousal and valence

Pearson product–moment correlations were determined between the established arousal ratings for each image and the quantified behavioral measure of drumming response. We observed a positive correlation ($r = 0.37$), indicating that drumming responses increased with more arousing image stimuli (Figure 5A). Pearson product–moment correlations were also determined between the established valence ratings for each image and the quantified drumming response. We observed a negative correlation ($r = -0.22$), indicating that drumming responses decreased with more positive-mood image stimuli (Figure 5B).

Neural responses to drumming (sending) and listening (receiving)

In this contrast comparison of drumming ('sending') and listening ('receiving'), we convolved the strike-by-strike drum intensities with the hemodynamic response function of the block (Figure 6). Contrast comparisons of listening > drumming (blue) show activity in the right hemisphere that correlates with greater amplitude and frequency of drum response, including supramarginal gyrus (SMG) (BA40), superior temporal gyrus (STG) (BA22), angular gyrus (BA39), STG (BA22) and middle temporal gyrus (BA21). These regions are included in the TPJ. On the other hand, comparisons of drumming > listening (red) show activity in two clusters, one in each hemisphere, that correlate with greater amplitude and frequency of drum response. The cluster on the right hemisphere has a spatial distribution including pre-motor and supplementary motor (BA6) and primary somatosensory cortex (BA1,2,3). The cluster on the left has a spatial distribution including pre-motor and supplementary motor cortex (BA6). Together, they are labeled Sensory Motor Cortex (SMC).

Comparison of drumming and talking

Contrast comparisons of drumming > talking show both left and right hemisphere activity (Figure 7). The spatial distribution of

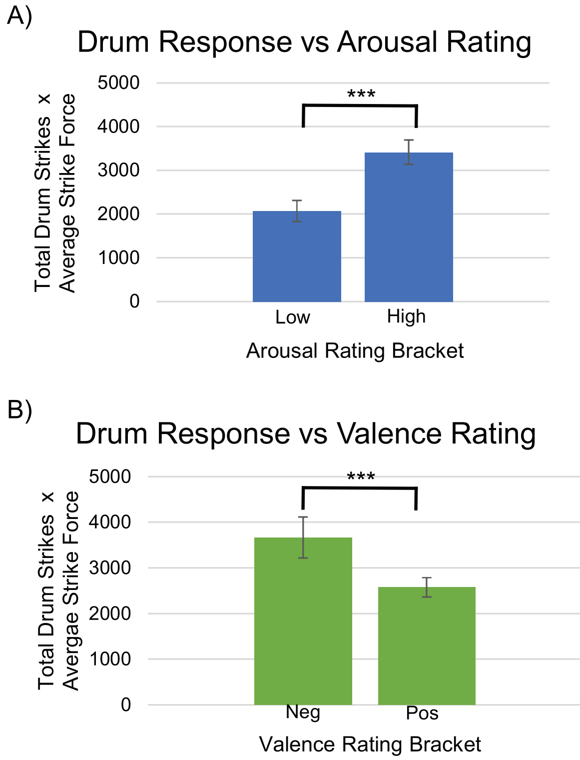

Fig. 5. A, A positive correlation ($r = 0.37$) was observed between the quantified drumming response (number of drum strikes multiplied by average drum strike force) and the arousal ratings of IAPS image stimuli. The bars represent two brackets equally dividing our range of IAPS image stimuli arousal ratings (lowest arousal 2.63 to highest arousal 7.35), $P < 0.001$. B, A negative correlation ($r = -0.22$) was observed between the quantified drumming response (number of drum strikes multiplied by average drum strike force) and the valence ratings of IAPS image stimuli. The bars represent two brackets equally dividing our range of IAPS image stimuli valence ratings (lowest valence 2.16 to highest valence 8.34), $P < 0.001$.

the right hemisphere cluster included the SMG (BA 40), the STG (BA 22) and the primary somatosensory cortex (BA 2). The spatial distribution of the left hemisphere cluster included the primary somatosensory cortex (BA 2) and the SMG (BA 40).

Discussion

In this study, we aimed to understand the neural mechanisms that underlie the communication of emotional qualities through drumming, a nonverbal auditory mode of communication. Our neuroimaging system using fNIRS and natural interpersonal interaction between dyads enables the study of ecologically valid communication. We hypothesized that strike-by-strike drum measures that communicate expressions of valence and arousal would elicit activity in brain systems associated with social and emotional functions, i.e. the right TPJ. We also hypothesized that drumming in response to emotional stimuli would elicit neural activity that was distinct from or greater than talking in response to the same stimuli in the right TPJ.

Using behavioral measures, we identified that increased frequency and amplitude of strike-by-strike drum behavior was positively correlated with image arousal and negatively correlated with image valence. We also found that increased frequency and amplitude of strike-by-strike drum behavior was correlated with sensorimotor activity in the 'sender' but TPJ activity in the 'listener'. Taken together, these findings support the conclusion that communication of emotion via drumming engages the right TPJ and that drumming may communicate both arousal and valence with some preference for arousal. Finally, we observed a greater cortical response in the drumming condition than in the talking condition at the right TPJ, including STG and SMG, suggesting that drumming not only activates this social–emotional brain region, but may have a distinct advantage in activating this area over talking.

Communicating arousal and valence

Specific features of drumming may explain its capacity to communicate arousal and valence, with some preference for arousal. In speech, various prosodic features are known to cue emotion, including loudness, rate, rate variability, pitch contours, and pitch variability (Banse and Scherer, 1996; Koike *et al.*, 1998; Juslin and Laukka, 2003; Ilie and Thompson, 2006). Similarly, such features in music include tempo, mode, melodic range, articulation, loudness and pitch (Gabrielsson and Lindström, 2001; Juslin and Laukka, 2003; Jonghwa Kim and André, 2008; Eerola *et al.*, 2013). Prior studies across both speech and music suggest that cues like articulation, loudness, tempo and rhythm tend to influence arousal, while mode, pitch, harmony and melodic complexity influence valence (Husain *et al.*, 2002; Ilie and Thompson, 2006; Jonghwa Kim and André, 2008; Gabrielsson and Lindström, 2010). Drumming has limited pitch or melodic capacity; on the other hand, cues like tempo, loudness and articulation are easily enacted through drumming, and these have been shown to allow a listener to reliably identify particular emotions via drumming (Laukka and Gabrielsson, 2000).

The importance of the right TPJ

The right TPJ, including the STG and SMG, is well established in its social and emotional function (Carter and Huettel, 2013). In a recent example using dual-brain fNIRS, the right TPJ has been directly implicated in functional connectivity during human-to-human *vs* human-to-computer competitive interaction (Piva *et al.*, 2017), consistent with dedicated human social function (Hirsch *et al.*, 2018). The superior temporal sulcus and gyrus were an early hypothesized node in the social network (Brothers, 1990), and this was substantiated by later research (Allison *et al.*, 2000; Frith, 2007; Pelphrey and Carter, 2008). For example, this region appears to play a role in interpreting biological motion to attribute intention and goals to others (Allison *et al.*, 2000; Adolphs, 2003), consistent with the Theory of Mind model of the TPJ.

The social role of the STG has been further investigated within the context of emotion (Narumoto *et al.*, 2001). Robins *et al.* (2009) observed increase right STG (rSTG) activation with emotional stimuli; this was especially increased for combined audio-visual stimuli as opposed to either audio or visual stimuli alone, highlighting the importance of the rSTG in processing emotional information in live, natural social interaction. In terms of specifically auditory stimuli, Leitman *et al.* (2010) also observed greater activity in the posterior STG with increased saliency of emotion-specific acoustic cues in speech, and Plichta *et al.* (2011) observed auditory cortex activation (within STG) that was modulated by extremes of valence in emotionally salient soundbites. Still more relevant to our investigation, the emotional processing of pleasant and unpleasant music has been lateralized and localized to the rSTG (Zatorre, 1988; Zatorre *et al.*, 1992; Blood *et al.*, 1999). Although

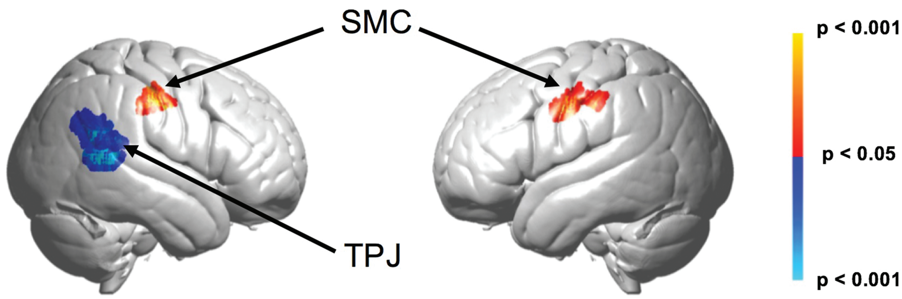

Fig. 6. Convolving strike by strike drumming intensities with the hemodynamic response function for the drumming ('sending') block, the listening condition shows greater activity than the drumming condition in two loci (blue), both in the right hemisphere. The first peak voxel was located at 64, −52, 24 ($T = -3.49$, $P < 0.00078$, $P < 0.05$ FDR corrected), and it included SMG (BA40) 49%, STG (BA22) 35% and angular gyrus (BA39) 16%. The second peak voxel was located at 64, −46, 6 ($T = -3.84$, $P < 0.00031$, $P < 0.05$ FDR corrected), and it included STG (BA22) 56% and middle temporal gyrus (BA21) 40%. In contrast, the drumming ('sending') condition shows greater activity than the listening ('receiving') condition in two loci (red), one in each hemisphere. The right hemisphere peak voxel was located at 60, −16, 42 ($T = 3.58$, $P < 0.00061$, $P < 0.05$ FDR corrected), and it included pre-motor and supplementary motor cortex (BA6) 43% and primary somatosensory cortex (BA 1, 2, 3) 18%, 12%, 17%. The left hemisphere peak voxel was located at −50, −6, 36 ($T = 3.11$, $P < 0.00211$), and it included pre-motor and supplementary motor cortex (BA6) 100%.

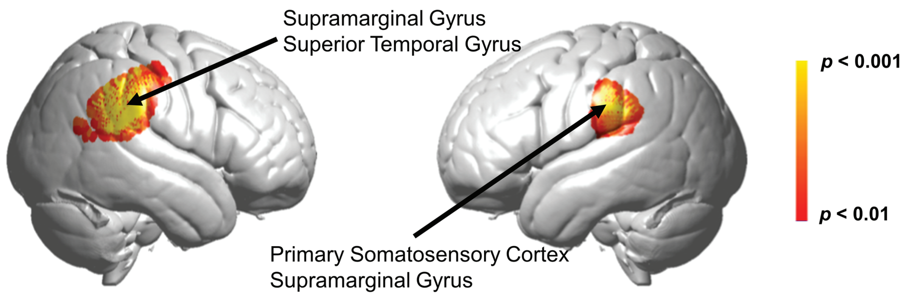

Fig. 7. Collapsing across qualities of valence and arousal, the drumming condition shows greater activity than the talking condition in two loci, one in each hemisphere, mapped in accordance with the NIRS-SPM atlas (Mazziotta et al., 2001; Tak et al., 2016). The right hemisphere peak voxel was located at 62, −36, 28 ($T = 5.32$, $P < 0.00001$, $P < 0.05$ FDR corrected), and it included SMG (BA 40) 41%, STG (BA 22) 25% and primary somatosensory cortex (BA 2) 21%. The cluster in the left hemisphere had a peak voxel at −66, −30, 30 ($T = 3.78$, $P = 0.00030$, $P < 0.05$ FDR corrected), spatial distribution including primary somatosensory cortex (BA 2) 42% (BA 2) and SMG 20% (BA 40).

drumming does not have the same range of affective cues as other music, our investigation replicates the known sensitivity of rSTG to emotion in music through fewer cues like tempo, loudness and rhythmic characteristics.

The SMG, the other region of the TPJ that plays a significant role in our findings, has also been implicated in social and emotional processing. Activity in the SMG has been associated with empathy and understanding the emotions held by others, suggesting a process of internal qualitative representation to facilitate empathy (Lawrence et al., 2006). Further, there is increased SMG activity particularly on the right side, when one's own mental state is different from the mental state of another person with whom we are empathizing (Silani et al., 2013).

The TPJ is relevant from a clinical perspective as well. In particular, the STG has been increasingly studied in patients on the autism spectrum given the deficits of both language and social interaction. Decreased capacity to attribute the mental states of animated objects in autism spectrum disorder has been linked to decreased activation of mentalizing networks, including the STG (Castelli et al., 2002). Many other autism studies have shown abnormalities in the rSTG, both functional (Boddaert and Zilbovicius, 2002) and anatomical (Zilbovicius et al., 1995; Casanova et al., 2002; Jou et al., 2010).

Volume loss of rSTG has been noted in those with criminal psychopathy (Müller et al., 2008), perhaps underlying their abnormal emotional responsiveness. Volume increases in rSTG on the other hand have been demonstrated in pediatric general anxiety disorder (De Bellis et al., 2002), in subjects exposed to parental verbal abuse (Tomoda et al., 2011), and in maltreated children and adolescents with post-traumatic stress disorder (PTSD; De Bellis et al., 2002).

Clinical application of drumming: future directions

Music and music therapy have been used in a number of clinical contexts, particularly emotional and behavioral disorders such as schizophrenia (Talwar et al., 2006; Peng et al., 2010), depression (Maratos et al., 2008; Erkkilä et al., 2011) and substance use disorders (Cevasco et al., 2005; Baker et al., 2007). Music therapy is perhaps best known for its utility in autism (Møller et al., 2002; Reschke-Hernández, 2011; Srinivasan and Bhat, 2013), where it has been used to improve emotional and social capacities (Kim et al., 2009; LaGasse, 2014). Given the aforementioned rSTG abnormalities in autism as well as our rSTG results, further research should explore neural correlates and possible neuroplastic effects of music interventions for social and emotional development in autism. Perhaps this may explain the consistent inclusion of drumming in autism music therapy and the special attention paid to rhythmic and motor aspects of music in autism (Wan et al., 2011; Srinivasan and Bhat, 2013).

However, while drumming has a number of musical elements and is often a part of group music-making, drumming and music are not identical. While music has been well established to cue both arousal and valence, we demonstrated the capacity for drumming to communicate arousal better than valence. This suggests that drumming interventions may be more effective for psychopathology typically associated with arousal (e.g. anxiety disorders, like PTSD) than for psychopathology typically associated with valence (e.g. mood disorders, like depression).

Recent work that used drumming in clinical populations substantiates this hypothesis. Bensimon *et al.* (2008) found drumming to be an effective intervention for PTSD patients by reducing symptoms, facilitating 'non-intimidating access to traumatic memories' and allowing for a regained sense of self-control and for release of anger. In another study, the effectiveness of drumming for substance use disorder was heavily linked to its ability to induce relaxation and 'release' emotional trauma (Winkelman, 2003). Interestingly, both of these studies highlighted the effect of drumming on increased sense of belonging, intimacy and connectedness, perhaps a reflection of our own cross-brain coherence findings. Further investigation of drumming in high arousal and high anxiety disorders within a neuroscientific framework could improve specificity and efficacy of treatment of these disorders, particularly within social contexts.

Limitations

Limitations of fNIRS investigations are balanced with advantages that enable dual-brain imaging in live, natural, face-to-face conditions. This study is the first to our knowledge to investigate the neural correlates of nonverbal auditory communication of emotion in an ecologically valid setting. One unavoidable limitation is the restriction of fNIRS data acquisition to cortical activity, due to limited penetration of infrared light through the skull. This excludes important limbic and striatal structures, which are known to be active in musical induction and perception of emotion (Blood and Zatorre, 2001; Brown *et al.*, 2004; Koelsch, 2010; Peretz *et al.*, 2013).

In terms of our behavioral data, while we noted a correlation between drum response and both arousal and valence, the negative correlation observed between drum response and valence may actually be due to arousal. The arousal and valence distributions of our IAPS subset (Figure S1 Supplementary Materials) indicate a relative lack of images with low valence and low arousal. This bias, which reflects a similar bias in the complete IAPS image set, results in an overemphasis of low valence images with high arousal, potentially mediating the negative correlation observed where drum response increases with lower valence.

In the comparison of drumming and talking conditions, we recognize that the elicited region of greater TPJ activation in drumming likely contains some contributory activation from nearby SMC, as expected from a drumming task. That said, the higher probability of TPJ regions noted by our digitizing process, as well as the breadth and significance of the observed neural activity in this area, provides confidence that there is a strong component of TPJ activation in drumming over talking. This speculative result invites further investigation into the utility of drumming over talking as communication modality with clinical application that elicits social–emotional engagement.

Finally, our subject population of mostly college students may limit generalizability. In particular, while drum experience was very low, there was a moderate level of averaged musical expertise that may have facilitated subjects' drum communication of emotion (Methods, Table 1). Further research should replicate these results in both a drum-naïve and music-naïve population.

Our study demonstrated the particular contribution of drumming to emotional communication that is associated with activity in the right TPJ. The observed sensitivity of the STG and SMG within the right TPJ during listening, a canonical social and emotion processing center, holds implications for social–emotional psychopathology. Future research on nonverbal auditory communication in clinical contexts, ranging from autism to PTSD, is informed by these findings.

Supplementary data

Supplementary data are available at *SCAN* online.

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