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Measuring Musical Engagement
Using Expressive Movement and EEG Brain Dynamics

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Abstract

We have developed a method for studying musical engagement using simple expressive rhythmic ‘conducting’ gestures matching the musical pulse. Expert and non-expert participants attempted to communicate the feeling of heard musical excerpts using simple rhythmic U-shaped hand/arm `conducting' gestures that animated, in real time, the movement of a spot of light on a video display while body motion capture and high-density EEG recorded their hand/arm movements and brain activity. The animations were intended to focus and simplify the conductors’ hand movements. A web-based pool of viewers then rated the recorded moving-spot animations using a musical affect rating scale. Affective ratings of the musical excerpts by conductor and viewer groups were correlated. Statistically significant differences were found in both the motion capture and the EEG data between the fully ‘engaged’ condition described above and a ‘less musically engaged’ condition in which conductors concurrently performed a mental dual distractor task. A theta/alpha-band EEG power increase in or near right parietal-temporal-occipital (PTO) junction before onsets of left-to-right swings appeared only in the fully engaged condition. Our results support: 1) Musical feeling and engagement can be communicated by rhythmic musical gestures alone, even after their reduction to a simple point-light display. 2) EEG brain activity in or near the right PTO junction appears to support affective gestural communication. 3) Expressive rhythmic gesturing does not seem to interfere with musical engagement, a possible advantage over other methods used to measure emotional engagement during music listening.

Introduction

The research reported here examines the behavior and brain dynamics supporting the experience of musical engagement, defined here as the experience of consciously “entering into” the experience of music as it is heard, imagined, or performed, a condition in which the listener is fully attentive to and emotionally engaged in the flow of musical material and feeling and not attentive to extra-musical stimuli or concerns. This may occur when listeners are actively involved in creatively experiencing the musical stimulus they are hearing or imagining, and also when they are shaping or helping shape the musical experience through performing, improvising, or actively modulating the sound environment to enhance their own and others' musical experience.

The intent of artistic musical performance is to allow, invite, and encourage listeners to readily and fully enter into a musically engaged listening state. The musical artist must not only avoid playing notes that are physically ‘wrong’ or out-of-place but must also create a sense in the listeners of an emotionally conducive musical ‘flow’ or ‘pulse’ whose importance was discussed by Manfred Clynes nearly 40 years ago (Clynes, 1977).

The nature of this temporal flow is not understood, though it is intuitively experienced by musicians – as evidenced, for example, by the success of conductors who use continuous gestures to control the ‘pulse’ of an orchestral performance, even though the notes the orchestral instruments are playing typically have abrupt onsets and physically a pulsatile rather than a smooth-flowing texture. That is, the listeners’ experience of ‘musical flow’ and continuous rhythmic pulse is created by the listener through their musical engagement based on the stream of physical sensations produced by the musician(s)--who are also creating their own experience of musical flow as they produce the music.

Clynes pointed to the flowing performance gestures of classical pianists and other musicians as expressing the continuous flow of musical feeling they are attempting to themselves experience more completely and to convey to listeners through the music they are creating. Though these gestures may have no direct effect on the sounds produced by their instrument, both performers and listeners interpret these gestures, like the flowing movements of orchestral conductors, as augmenting the affective musical experience and communication of the musicians as well as the affective musical experience of listeners.

Our goal is to better understand the state of musical engagement that can arise during physically engaged musical performance. Through the experiments outlined below, we attempt to clarify relationships between the experience of musical emotion or affect and physical movements during states of musical engagement. The resulting conclusions about musical engagement may well have broader impact outside of cognitive neuroscience. A method for modeling brain and body dynamics accompanying musical engagement could have wide-ranging applications in fields of music and new media studies research and development, as well as broad applications to musical learning and therapy.

Defining Musical Engagement. Our working model of musical engagement involves listener (or musician) attention to and affective perception of the music as well as musician or 'conductor' rhythmic action production, each of which is dependent on the others, though they relate to different aspects of brain and behavior. A framework for understanding affective communication through music should begin with our need and ability to read the emotional tone, reactions, and intentions of others. The psychologist Carl Meyers recorded the verbal descriptions of listeners' experience of listening to recorded excerpts of orchestral music. In his 1927 report, he described a major category of listener responses as describing perception of 'human character.' (Meyers, 1927).

In our experiments, we used a 'guided imagery' approach to suggest our 'conductor' participants imagine that their 'conducting' gestures, transduced into a simple point-light display, were being viewed in another room by a 'deaf friend' who wanted to share in the conductor's affective experience of the music they were hearing. We thereby asked the conductors to attempt to communicate their affective experience of the music they heard *to another person* in a spontaneous manner, i.e., by varying dynamic details of their simple rhythmic U-shaped 'conducting' gestures. Here we enclose the term 'conducting' in single quotes to distinguish the intended communicative rhythmic gestures made by our 'conductors' from the practice of actual musical conductors, who must balance several musical goals including affective communication.

Previous approaches to measuring emotional responses to music. Previous literature has attempted to describe the state of engaged music listening using concepts such as 'tension' and 'expectation' (Meyer, 1956) 'activation' (Zentner, Grandjean, & Scherer, 2008) and 'flow' (Csikszentmihalyi, 1990). Numerous studies have been conducted to define methods by which emotional responses to music can be measured, drawing on other psychological and neurological experiments (Eerola & Vuoskoski, 2013). As our model of musical engagement focuses on the real-time engagement of the listener, we are concerned primarily with studies in which participants provided continuous reports of their affective experience as they listened to music.

A continuous manual self-report approach, first used by Nielsen in a study of musical tension (Nielsen, 1983), was replicated by Masen and Fredrickson using an electrical dial input device (Madsen & Fredrickson, 1993). It was extended to the use of a two-dimensional input based on an emotion model by Schubert (Schubert, 1999) and Nagel (Nagel, Kopiez, Grewe, & Altenmüller, 2007). Krumhansl found convincing evidence that the self-report data obtained by this method are replicable and correlate with other measures of emotion. She used a computer interface to continually record listeners' responses to emotional music stimuli as they listened (Krumhansl, 1996), and found that their measurements of musical 'tension' as they listened to the first movement of a Mozart piano sonata correlated with the structure of the music as defined by Lerdahl's Tree Model (Krumhansl, 2002).

In separate experiments, she found that their ratings of perceived 'tension' in various music excerpts correlated with changes in their skin conductance level (SCL) and heart rate (Krumhansl, 1997). Timmers et al. (Timmers, Marolt, Camurri, & Volpe, 2006) presented to participants video and/or audio recordings of three performances of a Scriabin piano etude, and asked them to rate their emotional engagement with the performance in real time. The participants' emotional engagement was found to correlate with the measured dynamics of the performance they viewed.

These manual coding approaches force listeners to constantly monitor and symbolically code their affective experience, a meta-cognitive act that intuition tells us must impede listener emotional engagement with the music. Zentner reported anecdotally that participants in his continuous report studies were not able to listen, monitor their emotions, and complete the physical task of coding their emotion experience simultaneously (Zentner & Eerola, 2010). In other words, the self-monitoring and manual coding tasks added a cognitive load that interfered with participants' engagement in the music.

Such reports and intuition are compatible with observations of the role of anterior cingulate cortex (ACC) in the regulation of affective and cognitive states (Mohanty et al., 2007). In particular, functional brain imaging studies have shown that selective motor-response selection tasks, such as the self-report paradigm presented above, when completed in the presence of competing streams of information, activate the cognitive ACC division (dorsal ACC) while suppressing activity in the (more frontal, peri-genual) affective ACC subdivision (Bush, Luu, & Posner, 2000).

Cognitive evaluation (meta-evaluation) can interfere with other types of emotional response. Mazziotta et al. found that hemispheric balance of activation as measured by positron emission tomography (PET), while listening to music, differed between musically naïve subjects (whose scans indicated right dominance) and more 'analytic' musicians (who exhibited mixed dominance) (Mazziotta, Phelps, & Carson, 1982). Taylor demonstrated that limbic (e.g., amgydala and insula) response to aversive pictures is decreased, compared to passive viewing, when participants are asked to explicitly appraise them on a pleasant/unpleasant scale, and Critchley found that limbic activation decreased when participants are asked to report on the expressions of faces, as opposed to their gender (Critchley et al., 2000). Brattico found differing ERP responses to inappropriate chord sequences depending on whether subjects performed cognitive appraisal or subjective judgment tasks, and hypothesized that the different peak latencies represented differentiated systems for cognitive and affective music listening (Brattico, Jacobsen, De Baene, Glerean, & Tervaniemi, 2010).

Lastly, people are biased in their evaluations of behavior, tending to be much more willing to evaluate the traits of others than their own, and showing relative consensus in their judgments of others, while their self-assessments are often quite different than how others assess them (Wilson, 2002). Konecni cites "attribution theory" (Jones & Nisbett, 1971) to explain why continuous self-report of felt emotion is likely to break down under cognitive load, since participants tend to report what they perceive as the intended feeling of the music, rather than reporting their own internal feeling state (Konecni, 2008). The same problem seems likely to be as or more confounding when self-report is attempted *post hoc* rather than in real time.

The broad evidence that the cognitive load produced by asking listeners to symbolically self-report changes in their affective experience can interfere with emotional engagement warrants exploration into non-cognitive, non-symbolic means of indicating and measuring emotional engagement in musical listening tasks.

Measuring Musical Engagement. We developed an experiment protocol designed to 1) invite a music listener to naturally experience and concurrently communicate musical feeling in a laboratory setting, and 2) measure their engaged experience without requiring distracting self-report methods. Our study involved two experiments: First, we recorded the motion capture and EEG data from participants as they performed expressive gestures attempting to convey the feeling of the music they were hearing. Next, we played animated point-light displays transcribing their hand movements to an Internet viewer pool and asked them to rate the performances for musical engagement and conveyed affect.

I. An Expressive 'Conducting' Experiment

In the first, 'conducting' experiment, novice and expert music listeners were invited to make expressive U-shaped movements of their dominant hand and arm in time to music excerpts as we recorded their movements and EEG. In some trials we introduced an additional distractor task to attempt to reduce their level of engagement in the affective listening and communication task. We then analyzed their recorded movements and scalp EEG signals for patterns related to their level of music engagement.

Methods

Participants. Twenty-one right-handed participants, 13/8 male/female, were recruited from two different subject pools. The mean age over all 21 participants was 24.4 years with a standard deviation of 5.6 years. Special attention was paid to recruiting participants with a range of musical abilities, although no distinction between groups was made in the analysis. Eleven 'novice' participants (5 male, 6 female) were recruited from a general subject pool consisting mainly of university undergraduate students. Their combined years of experience in music and 10 other expressive movement disciplines was a mean of 6.6 years of training summed across all 11 disciplines, with a standard deviation of 6.8 years. Ten expert participants (8 male, 2 female) were recruited from graduate students in the UCSD Music Department. These expert participants had a mean of 28.8 years of training summed across all 11 disciplines, with a standard deviation of 12.1 years. Written informed consent was obtained from all participants. All experimental procedures were carried out following the University of California Institutional Review Board.

Musical Stimuli. During development of the conducting experiment protocol, in several pilot sessions we found that longer excerpts (> 30 seconds) posed two problems: First, the feeling intent of these excerpts was not uniform enough for the pilot participants to rate the excerpts consistently. Second, the tempo of the music changed over the course of the excerpts, making it hard to train novices to gesture in rhythm with the pulse of the music.

In the actual experiment, therefore, we used brief film music excerpts (< 30 seconds) that had been previously rated for feeling. Film music composers are adept at quickly eliciting emotional responses in their listeners. To accomplish this, film composers use musical sequences that are relatively simple and highly regular in rhythm. We selected ten film music excerpts, each about 15 seconds in length, from a corpus of soundtracks developed by Tuomas Eerola and Jonna K. Vuoskoski at the University of Jyväskylä, Finland (Eerola & Vuoskoski, 2011). Table 1 displays information about these samples, including the codes we use to refer to them in this discussion.

Table 1: **Label, Target Emotion, and Source information for excerpts used in the study.**

Present Study Code	Eerola Study code	Emotion Target	Album Name	Track	Min:Sec	Tempo (bpm)
2	26	Happy	The English Patient	7	00:33 - 00:58	65
3	38	Sad	Psycho	3	00:58 - 01:24	56
4	41	Sad	Big Fish	22	00:00 - 00:20	52
5	65	Tender	Road to Perdition	1	00:35 - 00:53	42
6	74	Tender	The Untouchables	9	00:04 - 00:23	73
7	92	Fear	Psycho	1	00:00 - 00:22	65
9	125	Anger	The Alien Trilogy	9	00:03 - 00:16	80
10	134	Anger	Shakespeare in Love	15	00:40 - 00:56	72
11	151	Surprise	The Rainmaker	5	00:00 - 00:16	68
12	241	High Energy	The Godfather	11	00:49 - 01:06	75

The samples in this database had been rated moderately or highly representative of five discrete emotions (Anger, Fear, Happiness, Sadness, Tenderness) and three bipolar emotion dimensions (valence, energy, and tension) by 116 novice music listeners on these eight music emotion dimensions (Eerola & Vuoskoski, 2011). The ten selected excerpts spanned this music emotion space, clustering into a high-energy, low valence cluster (circled in red in Figure 1 below) and a low-energy, high-valence cluster (circled in blue). Figure 1 plots the reported ratings of these excerpts (Eerola & Vuoskoski, 2011) on the valence and energy axes.

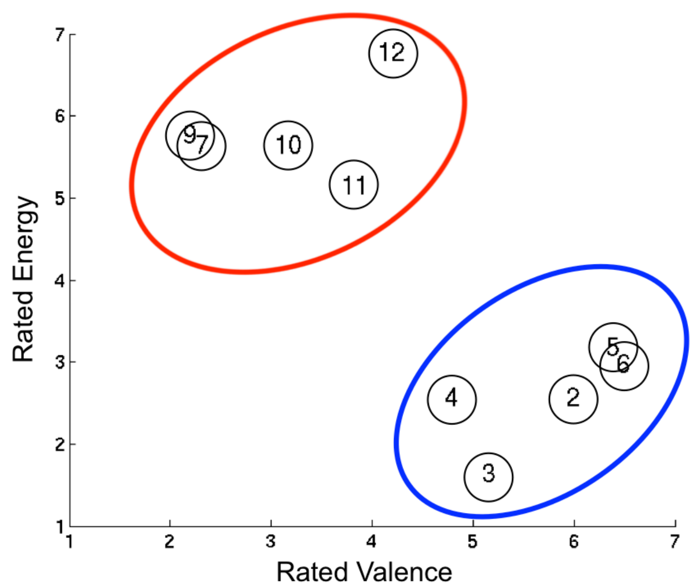

Figure 1. Reported ratings for the excerpts used in the experiment on valence and energy (from T. Eerola & Vuoskoski, 2011).

Data Recording. Two research assistants guided each participant in filling out the necessary paperwork and donning a PhaseSpace (San Leandro, CA) full-body motion capture suit (see

Figure 2 below). One additional PhaseSpace LED emitter was placed on the second joint of the middle finger of the participant's conducting hand. The 3-D position of the LED was streamed, via a computer script, to a real-time animation of the changing hand LED position as a moving white disc (with a dynamic 'tail') on a video display screen mounted on the wall facing the participant (see

Figure 2).

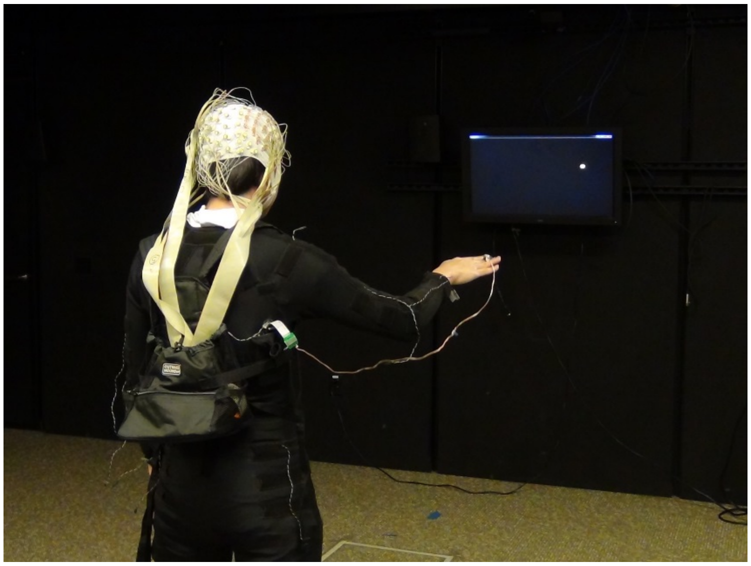

Figure 2. A participant wearing a 128-channel EEG cap and full-body motion capture suit with an addition LED sensor on the middle finger of his 'conducting' hand. His movements are animated as a moving white dot on a monitor screen facing him.

EEG data were collected using an Active II system (Biosemi, Amsterdam). Once seated in the SCCN Mobile Brain/Body Imaging (MoBI) lab, the assistants mounted a 128-channel EEG cap on the participant's head and digitized the relative 3-D positions of the electrodes using an ultrasound-based position tracking system (Zebris). Conductive gel was inserted into each plastic cap electrode well using a syringe with a blunt-tip needle to establish a sufficiently low-impedance connection between scalp and electrode.

Experiment Design and Stimulus Presentation. Next, the experimenter read the experiment description to the participant and then played a short excerpt from a 1968 motion picture, *The Heart is a Lonely Hunter,* in which one character uses expressive arm and hand gestures to illustrate the feeling quality of an orchestral music recording for another deaf character so that he might experience the feeling of the music**.** The participant was then invited to imagine a scenario similar to the one illustrated in the film excerpt – e.g., that they have a deaf friend in the adjacent room who is longing to share their experience of the music. We asked the participant to imagine that their friend was viewing their movements via a moving point light display projected on another video monitor.

The experimenter then demonstrated, as an example music excerpt was repeated, the desired conducting hand gesture, a U-shaped pattern (similar to the hand motion of an orchestral conductor conducting a simple two-beat (2/4) meter). The experimenter asked the participant to practice this gesture in rhythm with a heard music excerpt. If the participant did not produce the intended gesture, the experimenter gave further explanation and examples.

All further instructions to the participant were given by the experimenter via live audio feed from the adjacent control room. First, a guided relaxation induction script adapted from (Onton & Makeig, 2009) was read to the participant. This script, about 3 minutes in length, lead the participant through progressive body-part relaxation.

The 10 musical excerpts were then presented to the participant in three blocks (see Figure 3 below). To minimize the participant's cognitive difficulty in finding the rhythmic pulse of each excerpt, each was accompanied by a repeating "expressive metronome pulse" of enveloped pink noise imaginatively suggesting a repetitive, affectively neutral 'whoosh' of a conductor's baton. As illustrated in Figure 4 below, each excerpt was preceded and followed by four rhythmic pulses, which then continued during the excerpt, their volume first gradually decreasing to inaudible and then increasing again towards excerpt end. This pulse sequence was adapted to match the tempo of each musical excerpt. During excerpt playbacks, the participant repeated the U-shaped 'conducting' hand gesture in time to the pulse and music, 'shaping' the dynamic details of the gestures so as best to express the experienced musical feeling through the point-light display. To shape participant conducting gestures away from expressive multi-joint dance-like movements, the subjects were trained to keep their wrist angle constant as they conducted and asked them to focus their attention on the movement of the white dot on the video screen.

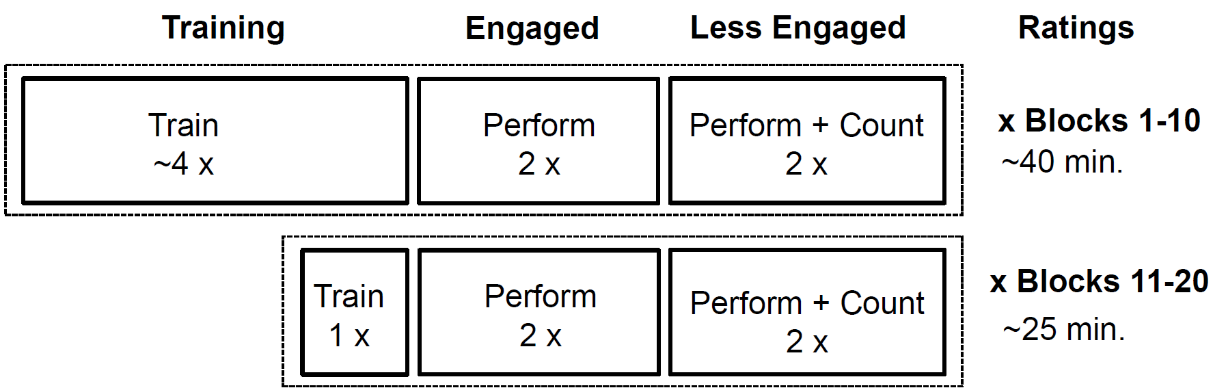

Figure 3. Each experiment session consisted of training, Engaged, and Less Engaged dual-task performance blocks in which participants were asked to perform the 'conducting' task while also focusing on a complex arithmetic working memory task. Following each of the first (upper) set of blocks, 'conductor' participants completed an emotion-rating questionnaire to rate the emotional quality of the musical excerpt. They then trained on communicating the next excerpt. After all 10 excerpts had been presented, a second round of presentations followed. These blocks used the same 10 musical excerpts; for each excerpt the participant was given only one rehearsal presentation, followed by two repetitions of Engaged performance and then a final performance bout (two repetitions) of the Less Engaged condition.

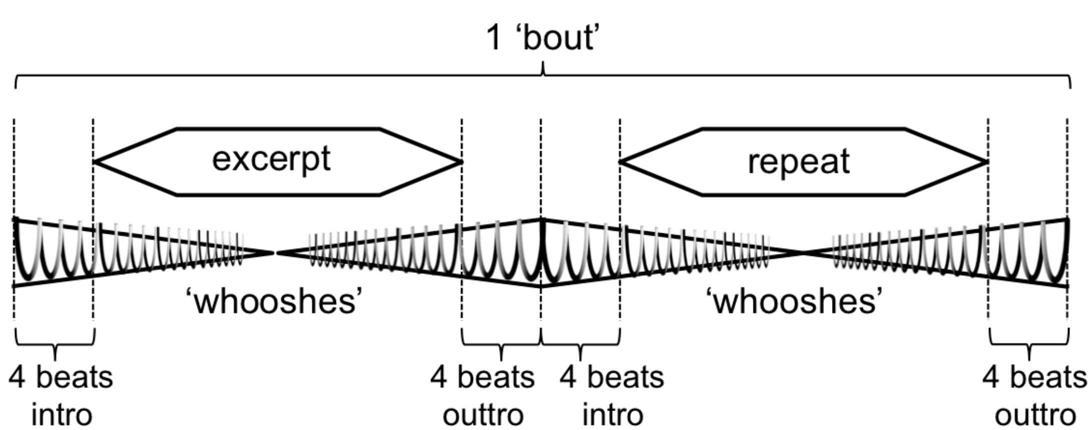

Figure 4. Each musical excerpt presentation was preceded by four repetitions of a bandpassed-noise 'whooshing' whose amplitude modulations were fit to the rhythmic pulse of

the musical excerpt. The background 'whooshes' were meant to indicate to the 'conductor' participant the tempo and timing of the intended rhythmic gestures. To help the 'conductor' maintain coherence of their gestures with the musical pulse, the 'whooshing' pulses were repeated during the musical excerpt with diminishing and then again increasing volume. Two presentations and accompanying gesture performances constituted a performance bout for each excerpt.

Excerpt presentations were separated into two sets of blocks to reduce possible fatigue effects. In the first set of performance blocks, the participant was allowed to repeat (so as to practice) conducting to the musical excerpt as many times as they wished until they were satisfied with their performance. When the participant indicated they felt they had completed a satisfactory performance run-through, they were asked to repeat their performance twice consecutively.

Then, the participant completed a 'Less Engaged' performance bout (also two repetitions of the excerpt) while simultaneously performing an engaging mental distractor task in which they had to convert the letters of a given word ("brain," "music," "mind," etc.) to integers corresponding to their positions in the alphabet (a=1, b=2, etc.), at the same time adding the corresponding numbers together to determine the sum total for the word. As pilot participants reported they frequently could not finish this task during the approximately minute-long 'Less Engaged' performance bouts, in the recorded experiments they were asked to complete as much of the task as possible.

After completing the training, performance, and dual-task trials for each musical excerpt, the participant filled out a short questionnaire asking him or her to evaluate the feeling of the excerpt on a five-point Likert scale ('Not at All,' 'Somewhat,' 'Moderately,' etc.) using the short-form Geneva Emotional Music Scale (GEMS-9) (Zentner et al., 2008), and to rate the excerpt for valence and arousal using the Self-Assessment Manikin (SAM) (Bradley & Lang, 1994).

The sequence of training performances and single-task (Engaged and Less Engaged) performances were repeated for each of the 10 music excerpts, as shown in Figure 3.

After a 5 to 10 minute break, a second set of blocks was performed, this time using only one training repetition for each excerpt, followed by another Engaged (2) performance bout, and then another Less Engaged (2) performance bout employing the same complex arithmetic working memory task. All non-training bouts were used in the final analysis. This experiment design yielded a total of 32 minutes of single-task, 'Engaged' condition listening data, and 32 minutes of dual-task, ‘Less Engaged' condition listening data.

Recorded Data Streams. EEG data were collected synchronously from 128 scalp, two infraocular, and two mastoid electrodes, with an active reference (Biosemi Active II) at a sampling rate of 512 Hz with 24-bit A/D resolution. Stimulus onset and offset of each music sample plus expressive metronome track were recorded in simultaneously acquired event channels. In addition, the participant's behavior was recorded both using a video camcorder and via 31 body motion capture channels. An additional PhaseSpace LED was placed on the second joint of the middle finger of the participant's conducting hand. The data stream containing the x, y, and z positions of the LED was streamed to a Producer program which animated the LED position as a point light display on a 43” monitor mounted on the wall facing the participant. Time codes were sent from a Macintosh running the automated Max/MSP (www.cycling74.com) playback script to the recording PC to indicate the beginning of each musical excerpt presentation.

EEG artifact removal. In an experiment like the one described above, the EEG signals collected are heavily contaminated by muscle signals and mechanical artifacts produced during arm and head movement. To disentangle brain and non-brain components of the EEG sensor data, the data were decomposed by Independent Component Analysis (Bell & Sejnowski, 1995). ICA estimates how hidden quasi-independent source processes (brain and non-brain) mix linearly via volume conduction and are summed at the scalp electrodes to produce the sensor data. When applied to EEG analysis, ICA has the capacity to separate out independent brain processes that are mixed by volume conduction in the scalp electrodes, as well as non-brain (artifact) contributions from eye movements, line noise, muscle activities, etc. (Makeig, Bell, Jung, & Sejnowski, 1996).

The success of ICA in separating brain source activities depends on the statistical source stationarity of the data, as well as how many artifact processes are allowed to remain in the decomposed data. Therefore, data cleaning is a critical part of the pipeline. In our processing pipeline, a 1-Hz high-pass filter was first applied to remove slow drift in the signal, followed by a notch filter at 60 Hz, 120 Hz, and 180 Hz to remove the noise induced by the power line and its higher harmonics. In both cases, zero-lag FIR filters were used to keep phase information intact. After filtering, periods of brief, high-amplitude artifacts were identified. A channel cross-correlation matrix was computed by passing a 2-sec sliding window across the entire session. Any data channel whose correlation with the other data channels was less than 0.45 for more than half of the session was removed from the analysis. Additionally, channels whose amplitude distribution kurtosis values were above 5 (i.e., differing markedly from a typical brain source process) (Delorme, Makeig, & Sejnowski, 2001) were marked as artifactual and removed from further analysis. The final step in the pre-processing was re-referencing the channels to their average.

EEG Data Analysis. To guarantee convergence of the decomposition, ICA was applied only to concatenated segments (1) in which the participant was performing the 'conducting' task and (2) were free of gross artifacts. To identify ICs representing the activity of a cortical source area, the best-fitting single equivalent dipole model was found for each IC scalp map (Delorme et al., 2011). Those equivalent dipole models that explained more than 85% of the variance of the IC scalp map were considered to represent the scalp projection of a brain source process. An IC whose scalp map strongly resembles the projection of an equivalent dipole can represent the net projected activity of a small patch of cortex whose local field potentials have spatiotemporal coherence (Delorme, Palmer, Onton, Oostenveld, & Makeig, 2012; Makeig & Onton, 2011). The equivalent dipole models were fit using the subject-specific sensor locations co-registered with a template 305-T1 brain from Montreal Neurological Institute. ICs with equivalent dipole models outside the brain volume (non-brain ICs representing scalp muscle or other non-brain artifacts) were rejected from further processing.

To explore source-level activity during arm swing cycles and possible differences between the Engaged and Less Engaged conditions, we computed a time-frequency decomposition of the activities of the remaining brain ICs into time-varying spectral power. To minimize border effects often obtained when doing spectral analysis in epoched data, we computed the time-frequency spectrograms of the continuous IC time courses, recovered by multiplying the ICA-learned source unmixing matrix by the high-pass filtered continuous EEG data. Time-frequency decomposition was performed using the continuous time wavelet transform (Mallat, 1999), (Kiebel, Tallon-Baudry, & Friston, 2005) using a complex Morlet with center frequency 1.5 and bandwith parameter 1 as a mother wavelet (Teolis, 1998). The scale parameter varied logarithmically between 7.68 and 768 to cover a frequency range between 1 Hz and 100 Hz. The logarithmic frequency scale was used to maximize frequency resolution at lower frequencies, suiting the 1/*f*-like spectral characteristic of EEG signals and the tendency for narrow-band EEG rhythms to occur at lower frequencies. Then, Event Related Spectral Perturbations (ERSP) were computed averaging trials of each condition after the mean log power spectrum of the condition was removed; this measure highlights event-related perturbations from baseline spectral activity (Makeig, 1993).

Since the different musical excerpts required conducting gestures with different durations, time/frequency measures time-locked to the repeated gesture (each right-to-left, then left-to-right swing cycle) could not be readily compared. To make this possible, we co-registered time/frequency ERSP matrices for each condition time by shrinking or expanding the time axis (*after* extracting power spectral perturbations), in essence transforming the x-axis from latency in seconds to fraction of the excerpt swing cycle. This process gave us ERSP matrices that were time-locked to each right-left-right swing cycle, and time-warped to have identical lengths.

Common brain processes were identified across subjects computing clusters based on IC equivalent dipole locations and swing-cycle ERSPs. A multidimensional cluster position vector was computed for each IC based on these measures, and thus a global distance matrix was created which characterized how far apart each pair of ICs were from one another in this space. For our calculations, after normalizing each variable we weighted the measures as follows: Dipole location, 10; ERSP, 2. Thus, the estimated dipole locations were given the highest priority. The k-means PCA-clustering algorithm (MacQueen et al., 1967) implemented in the freely available EEGLAB signal processing environment (Delorme & Makeig, 2004) was used to find 21 independent component clusters. This number was chosen such that on average, one IC per subject would be included in each cluster. Any ICs more than 3 standard deviations from any cluster centroid were then assigned to a designated 'outlier' cluster.

Next, each IC cluster was cleaned using visual inspection, by plotting the scalp map and spectrum of each IC included in the cluster. ICs with scalp maps indicative of muscle artifact or isolated channel artifacts were moved to the outlier cluster. ICs with peak activity in the 20-30 Hz range were also excluded from further analysis, since these likely accounted for scalp muscle signals.

At this point, the grand mean ERSP plots for each IC cluster were examined and cluster-mean ERSP differences between Engaged and Less Engaged conditions were computed. To correct for multiple comparisons, we applied a nonparametric permutation test originally developed for functional neuroimaging (Holmes, Blair, Watson, & Ford, 1996; Nichols & Holmes, 2001) and recently applied to ICA-decomposed EEG data (Miyakoshi, Kanayama, Iidaka, Ohira, & others, 2010).

Results

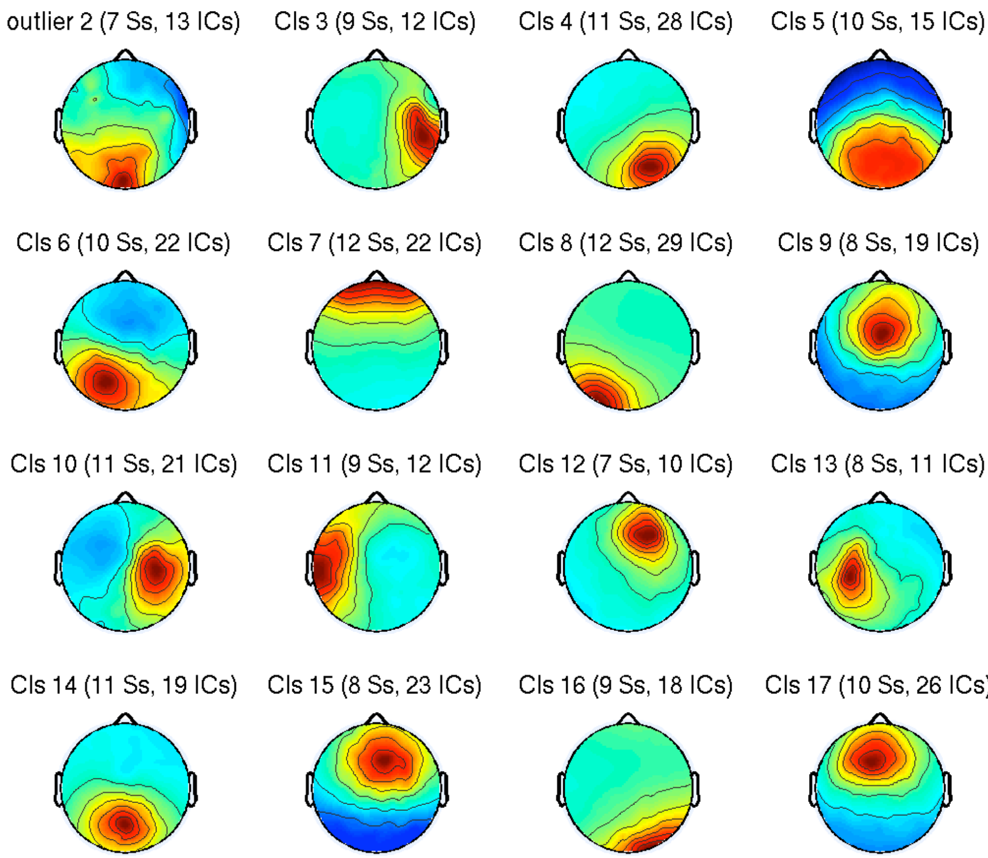

Figure 5. Maximally independent components were clustered across participants based on similarities in their equivalent dipole locations and length-normalized event-related ERSP measures time locked to the conductors' swing cycle. These topographic projections of each Independent Component (IC) cluster ("Cls") onto a scalp surface indicate the frontal, temporal, parietal, and occipital lobe locations of the cluster dipole centroids.

Figure 5 shows the results of IC clustering of brain ICs across all subjects in the analysis, plotted as mean topographic IC projections to the scalp surface. Figure 6 shows the locations of the 15 IC cluster centroids, as plotted in 3 dimensions, and projected onto a standard MRI image. Table 2 displays the MNI coordinates of the 15 IC cluster centroids, which lie in or near associational areas of the frontal, temporal, parietal, and limbic lobes, suggesting they relate to a complex interplay of brain functions associated with auditory and visual processing, motor planning, and emotional processing.

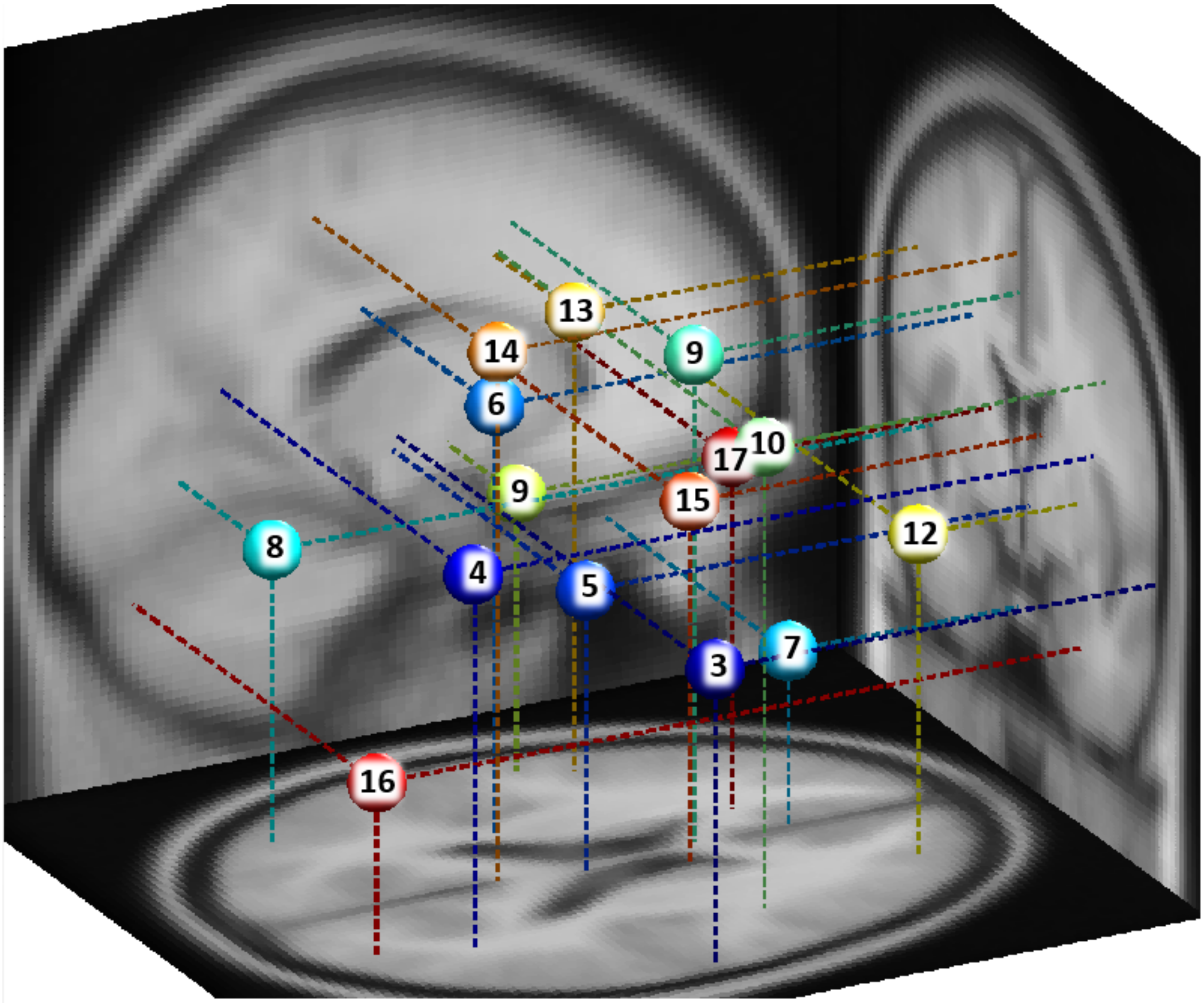

Figure 6. 3-D locations of the 15 brain independent component (IC) cluster centroids projected into a standard MRI template brain.

Table 2: 3-D locations of the 15 brain independent component cluster centroids, as MNI Coordinates.

	MNI Coordinates		
IC Cluster	**x**	**y**	**z**
3	34.39	-63.32	17.64
4	3.42	-19.80	-5.24
5	-24.49	-28.07	30.25
6	-1.90	33.03	-31.16
7	-43.71	-73.32	-2.72
8	-1.70	9.54	43.57
9	40.36	5.52	37.57
10	-56.15	-6.49	-6.20
11	28.14	49.92	4.20
12	-51.10	5.18	36.83
13	-0.86	-39.43	53.51
14	9.35	2.97	13.82
15	28.15	-84.14	-30.14
16	-15.42	25.82	11.40

Difference between Engaged and Less Engaged conditions. For each IC cluster we plotted the average swing-locked ERSP difference between the Engaged and Less Engaged conditions, masked at a $p < .01$ significance level. As might be expected, these cluster ERSPs time-locked to swing cycles exhibited a variety of EEG spectral perturbations. However, after significance testing and correction for multiple comparisons only right parietal Cluster 4 demonstrated a significant mean ERSP difference between the Engaged and Less Engaged conditions. In Cluster 4 (Figure 7), in the Engaged condition (3-4 Hz) low theta power increased near the beginning of the outward (R→L) phase of the swing cycle, and decreased near the beginning of the return (L→R) phase, relative to whole-trial baseline. Also, just before the return (L→R) swing cycle, in the Engaged condition (5-9 Hz) theta and low alpha power increased relative to the Less Engaged condition. This IC cluster is centered in or near Brodmann Area 39, the right angular gyrus of the parietal lobe, located near the top of the posterior temporal lobe. The lower right plot shows the locations of the dipoles contributing to this cluster within the template brain image.

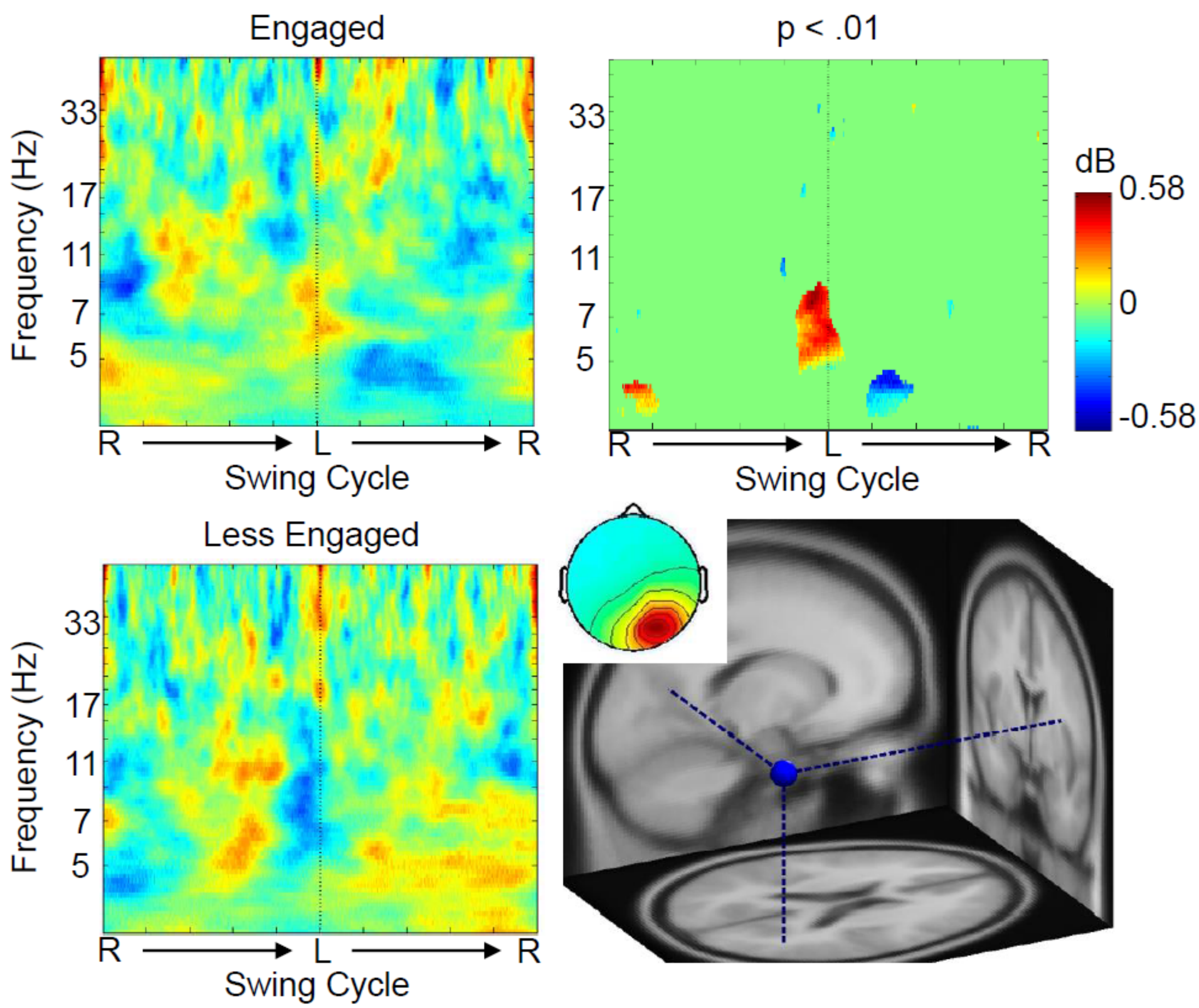

Figure 7. (Left column) Grand mean Cluster 4 event-related spectral perturbation (ERSP) images time locked to the R→L→R swing cycle in the Engaged and Less Engaged conditions. (Top right) The difference between the two ERSP plots, masked at a p <.05 significance level reveals significant differences near the beginning of each phase of the swing cycle and also before the return (L→R) phase. (Lower right) Centroid equivalent dipole location (in blue) for Cluster 4, plus (inset) the mean cluster scalp map.

Discussion – Experiment 1

The centroid of the IC Cluster 4 that exhibited an (Engaged - Less Engaged) condition effect is located in or near the parietal-temporal-occipital (PTO) association area of the right hemisphere, where the posterior, parietal, and occipital lobes meet, behind primary sensory and in front of visual association areas. Reports from functional neuroimaging show that this area is involved in higher-order cognition including motor planning, spatial awareness of bodily agency, and in awareness of others' experience. Its temporal lobe section (in the middle and inferior temporal gyrii) integrates visual and auditory information, while its posterior parietal subsection integrates visual and somatic information, making it an important area for executing complex motor plans.

Connectivity. PTO receives input from the somatosensory system concerning the locations of one's own body parts, and from visual and auditory areas supporting tracking the locations of nearby objects to be moved or avoided (Mendoza & Foundas, 2008). Signals are sent directly from posterior parietal cortex, where movements are planned and strategies executed (Andersen, Snyder, Bradley, & Xing, 1997), to the basal ganglia, which sends signals to initiate movements (Denny-Brown & Yanagisawa, 1976). The basal ganglia are in turn connected to motor cortex and cerebellum, which are involved in more detailed planning of motion trajectories (Alexander, DeLong, & Strick, 1986)(Marr, 1969)(Albus, 1971). These regions also communicate directly with brainstem and spinal cord centers where movements are executed by sending appropriate messages to the skeletal muscles.

Effects of Lesions. Lesions to the posterior parietal area result in sensory neglect, an impaired ability to attend to stimuli arising from the side of the body contralateral to the legion (Lezak, 2004), apraxia, the loss of ability to carry out complex planned movements such as reaching and grasping, and a more general loss of ability to perceive and remember spatial relationships (Culham & Kanwisher, 2001). Transcranial Magnetic Stimulation (TMS) applied bilaterally to the TPJ affects a participant's ability to intercept a moving visual target, suggesting that the TPJ is responsible for maintaining an internal model of gravity (Bosco, Carrozzo, & Lacquaniti, 2008).

Hemispheric Specialization. Both right and left PTO areas are associational areas of cortex, responsible for the integration of visual, auditory, and motor information. However, the PTO junction in the left hemisphere encompasses Wernicke's area, specialized for language comprehension (Kaan & Swaab, 2002)(Damasio, 1992). The right PTO supports spatial awareness and recognition of the spatial properties of visual percepts (Karnath, 2001).

Sense of Agency. Spatially detailed functional analyses of this area show that it is important for the sense of agency, the feeling that one is performing an action by controlled body movements. In an fMRI study of participants controlling an on-screen character whose movements periodically deviated from participant' instructions, activation was observed in the right TPO junction, suggesting that this area serves as the neural basis of sense of agency (Yomogida et al., 2010). In fMRI and PET studies of subjects controlling a virtual hand, the less the subject felt in control of its movements, the higher the level of activation in the right inferior parietal lobe (Farrer et al., 2003)(Leube, Knoblich, Erb, & Kircher, 2003). An fMRI study of schizophrenic patients showed increased activation of the right parietal area associated with pathological feelings that one's own movements originate outside one's control (Ganesan, Hunter, & Spence, 2005). A PET study demonstrated that discriminating between one's owns actions and those generated by others during a "perspective taking" exercise involves activation of right inferior parietal cortex (Ruby & Decety, 2001). In an fMRI experiment participants showed increased right rostral parietal activation when shown human versus dog actions, suggesting that actions that are part of the motor repertory of the observer are processed here, rather than other actions which are processed in more visual areas (Buccino et al., 2004). In addition, creating temporary "virtual lesions" in this area using transcranial magnetic stimulation (rTMS) interfered with participants' ability to determine if one's own movements were made by their own hand or by a virtual hand (Preston & Newport, 2008), and with discriminating self-faces from other familiar faces (Uddin, Molnar-Szakacs, Zaidel, & Iacoboni, 2006).

Theory of Mind. Other fMRI studies show that this area is critical for the formation of so-called 'theory of mind,' the capability to reason about another person's thoughts, important for social interaction (Decety & Lamm, 2007). A study of participants reading stories concerning physical details or mental states of characters, versus reading non-social control stories, showed that the right TPO junction was involved in reasoning about the contents of a character's mental processes as opposed to other socially relevant information (Saxe & Kanwisher, 2005). A similar fMRI task using non-verbal cartoons reached a similar conclusion (Vollm et al., 2006). Another fMRI study compared adults with autism spectrum disorder (ASD), known to have deficits in theory of mind, with healthy controls; both were given the task of making physical judgments and judgments about the mental states of two characters. In the control subjects the right temporal-parietal junction was selectively more active in the mentalizing task than in the physical judgment task. This distinction between tasks was not as present in the ASD subjects, with the degree of specialization anti-correlated with their degree of social impairment (Lombardo, Chakrabarti, Bullmore, & Baron-Cohen, 2011).

EEG Activity and Expressive Movement. We are not aware of any previous literature on localized sources of EEG activity during expressive movements. However, previous literature has reported links between alpha and theta activity and performance in other task paradigms involving music perception, emotion processing, and movement and action perception. For instance, theta rhythms have been associated with emotional experience in humans. ((Aftanas, Reva, Varlamov, Pavlov, & Makhnev, 2004); (Baçsar, Güntekin, & Öniz, 2006), (Doppelmayr, Stadler, Sauseng, Rachbauer, & Klimesch, 2003), (Knyazev, Bocharov, Levin, Savostyanov, & Slobodskoj-Plusnin, 2008), (Krause, Viemerö, Rosenqvist, Sillanmäki, & Aström, 2000); and frontal midline theta rhythm, in particular has been associated with emotional response to music (Sammler, Grigutsch, Fritz, & Koelsch, 2007), though it also appears in other contexts involving focused attention and perception of conflicting or reward-relevant information (Onton, Delorme, & Makeig, 2005).

EEG activity shifts over right parietal-temporal cortex have been associated with evaluation and interpretation of emotional information. ((Borod, Andelman, Obler, Tweedy, & Wilkowitz, 1992); (Davidson, 1984);). Reported effects include changes in alpha band (Heller, 1993),(Sarlo, Buodo, Poli, & Palomba, 2005), right parietal theta band (Aftanas et al., 2004), and gamma band activity (Balconi & Lucchiari, 2008), and shifts in left/right asymmetry of beta-band power (Schutter, Putman, Hermans, & van Honk, 2001) .

Frontal cortex, in contrast, may support the actual experience of emotion, as has been shown most clearly by studies associating interhemispheric differences in alpha power with different emotional states (Allen, Coan, & Nazarian, 2004; Schmidt & Trainor, 2001; Heller, 1993). Frontal scalp asymmetry favoring the left hemisphere has been demonstrated during feelings with positive valence, whereas more power is seen over the right hemisphere during negative valence emotional states (Sutton & Davidson, 1997; Davidson, 1992). These interhemispheric effects of experienced high and low valence transfer to the experience of music. The EEG of participants listening to music rated as exhibiting positive valence exhibits more alpha power power over left frontal scalp, and more alpha power over right frontal scalp for negative valence music (Altenmüller, Schürmann, Lim, & Parlitz, 2002; Schmidt & Trainor, 2001). Reports that only non-musicians showed an increase in alpha power at right scalp sites during music listening regardless of valence (Hirshkowitz, Earle, & Paley, 1978) suggests that the asymmetry effect in response to music listening indexes information processing as opposed to simple perception of the physical properties of the acoustic stimuli.

Low alpha (8-10 Hz) over temporal cortex is suppressed in reaction to perceived sounds (Lehtelä, Salmelin, & Hari, 1997), congruent with evidence that posterior alpha desynchronization is associated with visual attention (Klimesch, 1999). Elsewhere in the brain, attention to music relaxes attention to other non-relevant sensory channels, associated with increases in alpha power in relevant cortical areas. Levels of alpha power may change with cognitive shifts associated with experiment-provided changes in musical expectation (Fu et al., 2001), musical complexity (Günther et al., 1991), music imagination (Schaefer, Vlek, & Desain, 2011), and musical pitch memory (Van Dijk, Nieuwenhuis, & Jensen, 2010).

Alpha (8-12 Hz) band EEG recorded over sensorimotor cortex is normally suppressed during execution, action imagination, and action observation (Pineda, 2005). Decreased low alpha band spectral power (7.5–10.5 Hz) has been shown to be associated with both observation and execution of finger movements (Cochin, Barthelemy, Roux, & Martineau, 1999). This phenomenon is referred to in the literature as mu-rhythm suppression.

However, nearly all previous EEG research, including that on left/right alpha asymmetry, has failed to distinguish EEG brain sources from their broad scalp projections. In particular, alpha power over left frontal scalp undoubtedly includes strong contributions from left somatomotor mu-rhythm activity, etc. Interpretation of the source distribution of EEG phenomena measured at scalp channels should therefore always be accompanied by strong caveats, whereas source separation based on ICA or other data-driven spatial filtering methods can provide much more reliable source estimates.

Increased coherence in the low alpha band and theta bands between scalp sensors over primary and premotor cortex, supplementary motor area and posterior parietal cortices was observed during an action observation task (Holz, Doppelmayr, Klimesch, & Sauseng, 2008), suggesting -- but again, because of broad spread of activity from sources to scalp sensors, not demonstrating -- coupling of activities in these areas supporting action perception. This and other experimental evidence support the idea that simultaneous appearance and temporal coherence of brief theta band complexes in multiple cortical areas is a means by which limbic and motor systems integrate sensorimotor information to plan appropriate motor behavior (Bland & Oddie, 2001). For instance, widespread, bilateral scalp projections of theta oscillations appeared more often when participants performed a virtual driving task (Caplan et al., 2003) or initiated body movements (Cruikshank, Singhal, Hueppelsheuser, & Caplan, 2012), compared to periods of self-imposed stillness, and the more difficult the motor task, the more frontal-parietal theta coupling was produced to support the task (Sauseng, Hoppe, Klimesch, Gerloff, & Hummel, 2007).

In particular, temporally aligned theta band bursts are thought to modulate the timing and therefore the impact of sparse neural spike-based signaling between non-adjacent brain areas, as evidenced by phase-amplitude coupling of high-frequency broadband activity at select phases of temporally coordinated theta rhythm cycles (Canolty & Knight, 2010). It could therefore be of interest to further examine our data for expressive movement-related changes in theta band coherence and phase-amplitude coupling.

Conclusion. We recorded the movements of our experiment participants during an expressive listening task, and analyzed the position and acceleration profiles of the resulting movement traces. Analysis of EEG data recorded during the experiment demonstrated that, just before and after initiation of left- and right-going conducting swings, simultaneous performance of the distractor task altered mean EEG spectral activity in or near the right temporal-parietal-occipital (TPO) junction, an area whose activity relates to the sense of agency in performing movements and in knowing and affecting the mental experience of others. Specifically, during the Engaged conducting condition, an IC cluster in or near the right TPO junction exhibited more theta and low-alpha band EEG activity immediately before and after initiations of expressive conducting (swing) movements, than in the Less-Engaged (dual-task) condition.

Our results thus suggest that effective musical communication relies on cortical processing in or near the right TPO junction, which supports this communicative 'attention' (or 'intention'). Engagement in communicating musical feeling requires a consolidation of rhythmic action planning with emotional expression, which is then output as a motor execution. The right TPO junction may be involved in this consolidation process by supporting awareness and attention to the conducting movements' effects on the *mental experience* of the intended (here, imagined) recipient, immediately before and after the initiation of expressive movements.

Experiment 2: Viewer ratings of the silent point-light animations

In the first experiment, we determined that the participants, given the task of expressing the feeling of musical excerpts as they listened to them using repetitive hand/arm 'conducting' gestures, produced EEG spectral perturbations linked to their level of task engagement and expressive intent. In a second experiment, we showed volunteer Internet viewers silent, single point-of-light video animations derived from the motion capture data recorded as the conductors completed the expressive gesture task. These Internet-based study participants were asked to describe the musical feeling tone suggested to them by the silent animations, using a modified version of the GEMS-9 and valence-arousal questions given to the conducting study participants. The Internet viewers were also asked to compare pairs of animations from Engaged and Less Engaged conditions, deciding which animation best conveyed musical feeling.

We first asked whether the descriptions of the feeling of the individual excerpts in the conductor questionnaires and the Internet viewer questionnaires matched. If so, this would imply that the conductors were successful in communicating their affective musical experience. We also hypothesized that the Internet viewers would select the Engaged trial animations as better communicating the musical feeling of the conductor and the music than the Less Engaged condition animations. This would demonstrate that the movement dynamics conveying an engaged musical performance can be captured by a single point-light display. It would also imply that the dual-task Less Engaged condition did impede musical communication and, thereby likely conductors' musical engagement as well.

Methods

Following two small pilot Web-based experiments performed by personal contacts of the experimenters to select parameters for the final Web-based experiment, 90 volunteer Web-based participants were recruited via e-mail, Facebook, and Internet listings of available on-line psychological experiments. The mean age was 35, with a standard deviation of 14. 47/43 of the 90 participants were male/female; 93% were right-handed. All participants completed the Music Experience Survey given to the Conducting Experiment participants. The mean combined number of years of musical (and related) training for the Internet Experiment participants was 17.7 years, with a standard deviation of 28.5 years; this was comparable overall to the participants in Experiment 1, who reported a combined 17.2 years of training.

The motion-capture data from eight of the conducting experiment participants was processed into animations that were uploaded as YouTube videos (youtube.com). Using the freely available MoBILAB toolbox (Ojeda, Bigdely-Shamlo, & Makeig, submitted) we projected the three-dimensional finger marker motion capture data onto its two-dimensional principal subspace using principal component analysis (PCA). We then separated the motion capture data for each subject by music excerpt, and by condition (Engaged vs. Less Engaged), then segmented each performance into swing cycles defined by a swing towards the left followed by a swing towards the right, bringing the hand back to the starting position (R→L→R). We then averaged all swing cycles within the excerpt giving, for each subject, a single mean swing cycle characterizing the performance of the excerpt. This data treatment was chosen after completing two pilot experiments. For the first pilot (n=9), single trials were chosen from each conductor's performances of each excerpt, and no segmentation or averaging was performed on the data. For the second pilot (n=17), a similar procedure for swing segmentation was followed as described above, and then an additional normalization step was added, whereby the animations were slowed down or sped up to match a single tempo (the median inter-beat interval, 0.9 seconds), and the swing lengths were contracted or extended to match the average span. The results for these pilots are included with the main experiment results in Table 3.

We then animated the swing cycles by plotting a white disc on a black background with a trailing tail fading from white to black in 1 second, repeating the real-time display viewed by the conductors themselves. After excluding datasets with trials discarded because of missing data, 8 conductor datasets remained with a complete set of animations (one for each of the 10 music excerpts and two performance conditions, giving 8*10*2 = 160 animations). Six of the datasets were from novice conductors, the other two from experts. We repeated each mean swing cycle 10 times to create an extended mean performance video for each excerpt and conductor, and embedded these videos into an Internet survey script using the Survey Monkey web page building environment (*surveymonkey.com*).

Participating viewers first saw an introductory page explaining the experiment, followed by 20 pages each containing one of the embedded YouTube videos at the top of the page followed by a short questionnaire consisting asking the participant, "How well did the animation communicate to you a distinct musical feeling?,'' followed by the music feeling descriptors (the GEMS-9 scale and the Self-Assessment Mannikin cartoons illustrating valence and arousal) given to the conducting experiment participants. Each of the questions was answered by a response on the five-point Likert scale used in

Experiment 1. An unexpected technical difficulty compromised data collection of 'Tenderness' rating data.

The animations were chosen for each survey page as follows: The first four conductor datasets were assigned to the first two blocks, and the other four to the third and fourth blocks. Within each block, half the 20 music excerpt animations from two of the conductors were randomly distributed, half assigned to the first block and the other half to the second block. Each block also included the complementary half of the music excerpts the from the other two conductors, so each music excerpt was played the same number of times within each block. Within each survey, all of a first conductor's animations were presented consecutively, followed by a second conductor's animations, and so on. This allowed the Internet respondents to be able to adjust to the individual style of each conductor.

Viewing musical engagement. At the end of each block of five (same conductor) videos, a sixth page was presented. On this page, two videos were presented, one composed of the 10 concatenated mean swings from Engaged condition performances of a particular excerpt by the same conductor as the previous five videos, and the other the mean swings from this conductor's Less Engaged performances of the same excerpt. The subject was asked, "Which of the two animations below better communicates to you a distinct musical feeling?" Viewers indicated their answer by clicking a button placed above each video.

The survey responses for the rating questions were normalized both within subject and within question by subtracting the mean of all the participant's responses for that question across all music excerpts, and dividing by the standard deviation. This ensured that any participant's individual sensitivity to, for example, Sadness, would not skew the overall measure of Sadness across subjects.

Results

Correlation of Internet and Conductor Responses. We computed correlations between the responses given by the conductors after performing each music excerpt and the responses to the animated transcriptions of the performances themselves given by the Internet viewers. The results are shown in Table 3. Excerpt ratings for Transcendence, Power, Nostalgia, Peacefulness, and Arousal given by the two groups were well correlated ($p < .05$). An ANOVA testing the effects of Participant Group (Conductors vs. Viewers) and Excerpt Group (Excerpts 2-6 vs. Excerpts 7-12) on each of the 10 ratings demonstrated significant interactions between these factors for the rating scales of Wonder ($p < .05$), Transcendence (p < .005), and Nostalgia (p < .05). These results suggest that the significant correlations seen in the Power, Peacefulness, Activation, and Arousal ratings (for which no interaction with Excerpt Group were found) are likely due to the difference in perceived arousal that distinguishes the two excerpt groups. This makes intuitive sense, as all of these scales correlate (if not entirely) with perceived arousal. However, the correlations seen in the Wonder, Nostalgia, and Transcendence ratings are likely due to other factors that affect the way viewers interpreted these expressive movements.

Table 3: Correlation coefficients (r) between song ratings from Conductors and three Internet viewer groups. Results from Experiment 2 are shown in the left column (Mean Swings). The right two columns give results of two exploratory pilot experiments (see text).

	Mean Swings	**Full Perform.**	**Normalized**
Rating	**N=90**	**N=9**	**N=17**
Wonder	-0.02	-0.16	-0.52
Transcendence	**0.72***	-0.24	-0.19
Power	**0.73***	**0.92*******	0.26
Nostalgia	**0.88*******	**0.76***	0.38
Peacefulness	**0.78****	**0.83*****	0.39
Joyfulness	0.59	**0.67***	-0.06
Sadness	0.62	0.52	-0.11
Tension	0.51	0.52	-0.11
Valence	0.21	0.22	0.41
Arousal	**0.77****	**0.89*******	0.10

* : p < .05; ** : p < .01; *** : p < .005; **** : p < .001

Full versus mean swing animations. In pilot Internet viewing experiments involving nine viewers, full performances of the videos from the same conductors were used instead of concatenated average swings; the results from this experiment pilot are shown in the column of Table 3 under the heading [Full Perform.]. That only minor differences exists between these two sets of correlation results shows that the movement averaging and concatenating in the main experiment, which effectively 'smoothed out' the performance by repeating only the expressive variations recorded across all or most swings, did not appear to have a major effect on viewer ratings.

The swing averaging method may have had an effect on Joyfulness ratings, suggesting that some of the expressive variations along this rating dimension are contained in the degree or type of across-swing variability. However, swing averaging may have produced Viewer-Conductor correlation in Transcendence ratings not evident for the viewers of the full animations. Here, removing the single-swing information, thereby increasing the perceived regularity of the conductor movements, brought viewer's ratings along this dimension more in line with conductors' ratings.

Effects of duration/tempo. A second pilot experiment presented the concatenated swings normalized in duration across excerpts (so that each had the same excerpt-median swing cycle duration, 900 msec). The mean swing cycles were similarly normalized in excursion height and width. Seventeen Internet viewers took part. Their rating correlation results are shown in the [Normalized] column in Table 3. There was no significant correlation between the ratings given by the conducting participants and the pilot participants. Removing tempo and travel distance differences from the movement trajectories thus appeared to remove much of the information the audience experiment participants used to rate the animations.

Distinguishing Engaged from Less Engaged performances. The animations rating task added to the end of each conductor performance block comprised a two-alternative forced choice (2AFC) test. Viewer sensitivity to engagement, the proportion of correct 2AFC responses (Macmillan & Creelman, 2004) should here vary between 0.5 (random guessing) and 1.0 (perfect detection). For our experiment, sensitivity was 0.67. We confirmed that this statistic was significant by finding where it lay in the cumulative binomial distribution centered at 0.5, corresponding to the null hypothesis (H_o): that the subjects answered the forced-choice task at random. In our case, the actual result (60 of 90 trials) corresponds to a $p(H_o) = .0005$, confirming our hypothesis that differences in level of conductor "engagement" were detectable by the Internet viewers.

Conclusion. We confirmed our hypothesis that the affective ratings of the musical excerpts by the conductors themselves and by Internet viewers of their conducting performances would correlate significantly, demonstrating that the conductors were successful at the affective communication task. The forced-choice task showed that that movement dynamics characteristic of an engaged musical performance, regardless of feeling intention, could be captured by a repeating single point-light display. We also confirmed our hypothesis that the Internet viewers would identify Engaged condition animations as better communicating the feeling intention of the composer and conductor. This tells us that the dual-task condition was able to interrupt the (engaging) affective communication achieved by the conductors during Engaged conducting performance, supporting the result of the EEG analysis that conductor EEG activations time-locked to the conducting gestures itself were affected by less engaged dual-task performance.

General Discussion

Our two experiments sought to examine the interplay between attention and movement in the creation of musical engagement. This study was unprecedented in its analysis of EEG dynamics of participants engaged in expressive movement. By necessity, this first study was exploratory in nature, and would benefit from further study and replication.

For the most part, our data confirmed our basic hypotheses concerning communication of feeling intention through expressive gestures. First, we hypothesized that our 'conductor' participants would be able to convey the feeling intention of the music stimuli we played for them, as past studies have shown the power of expressive gestures in the conveying of musical emotion. In one such study, participants shown ballet performances were able to accurately judge the structure and emotional content of video-only performances, in comparison to the full audio-visual performances (Krumhansl & Schenck, 1997). In other experiments in which viewers were shown audio-visual or visual recordings of solo clarinet performances, they perceived the expressed emotion primarily from the visual channel (Wanderley, Vines, Middleton, McKay, & Hatch, 2005; Vines, Krumhansl, Wanderley, & Levitin, 2006). Specific emotions such as Happiness, Sadness, and Fear were accurately judged by viewers shown visual-only marimba performances (Dahl & Friberg, 2007). In our experiments, similarities of the Conductor (Experiment 1) and Viewer rating results (Experiment 2) showed that at very least some aspects of the feeling intent of music the 'conductors' were listening to was conveyed by their simple rhythmic expressive 'conducting' gestures.

Furthermore, we expected the feeling intentions of the conductors' expressive gestures could be preserved by translation into single point-light animations, as Davidson had demonstrated that point-light displays could capture expressivity in musical performance even more accurately than the audio recording of the performance (Davidson, 1993). This was confirmed by the significant similarity of the conductor and viewer ratings in Experiments 1 and 2 for the rating scales Nostalgia, Peacefulness, Arousal, Power, and Transcendence. These correlations suggest that feeling intention on these dimensions was conveyed by the conductor movements even after their translation into 10 exactly repeating (mean performance) swings of an animated white disk on a black background. In this study, to minimize the chance of the results being affected by individual subject differences we drew the music samples from a validated database (Eerola & Vuoskoski, 2011). However, since neither the emotional responses to the animations from the conducting group, nor the emotional responses to the music sample in the Internet viewer group were collected, we cannot know whether their music and animation ratings could have matched or not and thus do not know whether the discrepancy was due to the group difference or to processing difference.

Future studies may probe the extent to which these correlations depended on one or more movement characteristics. For instance, (Luck, Toiviainen, & Thompson, 2010) showed that continuous ratings of valence, arousal, power, and expression given to point-light displays of two conductors' performances correlated with measured amplitude, variance, and speed of the movements.

In a pilot experiment, we probed whether the conductors' feeling intentions would be accurately perceived by viewers after reduction to changes in acceleration within the movement cycle by normalizing for excerpt differences in excerpt tempo and in spatial extent of conductor excerpt performance. This did not prove to be the case: viewers clearly inferred affective quality from differences in tempo and possibly in excerpt-to-excerpt differences in the spatial extent of conductor performances.

However, in Experiment 2 viewers were able to select between fully and less engaged concatenated mean-swing performances of the same excerpt by the same conductor even though these animations did not differ in tempo. Further experiments that controlled for particular features of the animations, or degraded the visual information to various degrees could reveal which features are necessary to convey a particular emotion. For instance, Sevdalis and Keller (Sevdalis & Keller, 2012) showed that intended expressivity of dancers can be captured by point light displays as short as 200 ms in length.

Conversely, the work of Sievers et al. (Sievers, Polansky, Casey, & Wheatley, 2013) used a more sophisticated moving ball animation that changed shape, texture, and trajectory according to changes in a few expressive movement 'primitives.' Members of two different cultures mapped these features similarly, demonstrating that the structure of music and expressive movement share common features, and that the interpretation of these gestures crosses cultural boundaries.

We asked whether EEG differences might appear between Engaged and Less Engaged conditions that were time-locked to performance of the 'conducting' task. If so, we expected that the revealed location and nature of these brain dynamic differences would be plausibly consistent with fMRI research related to music engagement. A cluster of source-resolved and cortically co-located independent component EEG processes in or near right temporal-parietal-occipital (PTO) junction exhibited spectral changes time-locked to the initiation of the swing cycle movement. We tentatively interpret these as relating to the known involvement of this cortical area in the feeling of agency (control) of actions and in imagining the mental experience of others, both in line with our instructions to conductor participants to perform their gestures with a goal of conveying to an imagined deaf friend the feeling of the music being played to them.

Further, the obtained condition differences in spectral character of the EEG signals from this region were time-locked to just before each (R→L→R) swing phase in the U-shaped conducting movement cycle. This result demonstrates the value of combining EEG data collection with body motion capture, a modality we refer to as mobile brain/body imaging (MoBI) (Makeig, Gramann, Jung, Sejnowski, & Poizner, 2009) and the ability of joint movement/EEG analysis to reveal ways in which our brain dynamics are timed to support the cognitive and social goals of our motor behavior (in addition to producing and controlling the motor behavior itself).

Implications. Our experience in creating the engaged music listening experimental paradigm, and the motion capture, EEG, and affective rating results we have obtained using it have a number of implications for future research of musical (and possibly other) engagement. First, we found that guided imagery and relaxation exercises are useful tools for preparing listeners for engaged music listening in a laboratory environment, in line with previous experience (Onton & Makeig, 2009) and music therapy literature (Bonny & Savary, 1973). Future studies might compare different means of encouraging or inducing engaged music listening to firm this observation and further optimize the approach we introduced here.

Both humans and animals naturally express their affective state and responses, including empathic responses to other's expressed feelings, via bodily movements and gestures. Moreover, we typically do so without specific attention to our movements themselves. Expressive gesturing thus may not require a splitting of attention unless the movements involved themselves are highly technical, complex, or symbolic. The expressive rhythmic gesturing task we used here proved to be a useful tool both for focusing listeners' attention to the music and for allowing them to indicate their experience without introducing a separate, distracting cognitive task and while providing valuable behavioral data we here used to evaluate listener and viewer engagement and perceived musical affect. We hope our results might encourage further studies of expressive gesture and its connection to everyday experience – as well as in music, dance, or theatrical performance.

Future directions. We believe the non-invasive method for monitoring musical engagement we have introduced here could prove to be a generally useful tool for music perception research, with possible wider applications to music classification, technology, and therapy as well as to other affective perception and communication domains. A measure of engagement computed online from an EEG signal could also be useful for the creation of affective brain-computer interface (BCI) technology for the entertainment industry, including music recommendation services. Such a system could combine an active, affective gesture recognition system with an EEG-based affect classifier to create a hybrid music BCI. One form of such a system, recently engineered by first author Grace Leslie and Tim Mullen, operates both on covert EEG-based measurements of user emotional state (to control the mood of a musical mix), and overt gestural control (to allow the user to control musical form and style) (Leslie & Mullen, 2011). Commercially viable products of this form are easily imaginable, e.g., systems combining a now commercially available, low-cost, wearable EEG headset with a smart phone incorporating a 3-D accelerometer and gyroscope for gestural input with a music player, or incorporating now-available low-cost hand gesture recognition devices (www.leapmotion.com).

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