Hemispheric Specialization for Musical Structure Processing: A Dichotic Listening Study

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ABSTRACT

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In a dichotic listening study using a musical priming paradigm Hoch and Tillman (2010) found a left-ear advantage for the tonal function effect on spoken syllable identification, suggesting a right-hemispheric specialization for musical structure processing. A pilot study was performed using healthy right-handed non-musician participants to investigate the possible moderating effects of the Hoch and Tillman (2010) findings caused by alternating response hand as well as response key orientation. Several interactions were found which indicated that response hand and response key orientation moderated task performance. Modulations appeared to be due to a Coherence between response hand and response key orientation, as well as a possible interference occurring due to the contralateral processing of each hemi-field of internal visual representations of task response keys.

Hemispheric Specialization for Musical Structure Processing: A Dichotic Listening Study

One important question regarding human brain function has to do with why the human brain is divided into two separate hemispheres. It is known for example that verbal auditory material is primarily processed in the left hemisphere of the brain (Hugdahl et al., 1999; Kimura, 1967; Milner, 1962). More recent studies have suggested that nonverbal auditory stimuli, on the other hand, are processed primarily in the right hemisphere (Tervaniemi & Hugdahl, 2003). The current study investigated which hemisphere, if either, is specialized for the processing of musical auditory stimuli.

One key to understanding the processing of auditory stimuli is an understanding of the Contralateral Processing Pathway and how it can be used to infer hemisphere specialization in a Dichotic Listening Paradigm (DLP). When a stimulus is presented to the left ear, there are more projections to the auditory cortex of the right hemisphere; likewise, when a stimulus is presented to the right ear, there are more projections to the auditory cortex of the left hemisphere. A Dichotic Listening Paradigm takes advantage of these contralateral projections and is often used to study the lateralization of processing of auditory stimuli. In this paradigm, a subject listens to one stimulus in the left ear and a different stimulus in the right ear. Since each stimulus is being primarily sent to the opposite hemisphere of the brain, one can study how individual hemispheres process stimuli. For example, responses made to a stimuli being presented to the right ear reveal how a participant is processing the stimuli in the left hemisphere. Comparison of responses to a particular stimulus being presented to the left ear verses the right ear reveal differences in how the stimulus is being processed in the right hemisphere and left hemisphere respectively. For example, previous studies have shown a right-ear advantage (REA) for the processing of spoken syllables, which reflects a left-hemisphere specialization for verbal material processing (Hugdahl et al., 1999; Kimura, 1967).

Another important tool for studying musical auditory processing is the Musical Priming Paradigm. In a harmonic sequence, chords can build a level of expectancy which depends on how the chord is related to the harmonic sequence preceding it (Tillmann, 2005). This level of expectancy is determined using prior musical experience. A chord can be highly related or have an important tonal function. For example, a tonic chord which is based on the 1 chord in a particular key (e.g., c-major chord in the key of c) and is often used to resolve or finish a harmonic sequence and thus has a greater expectancy. Alternatively a chord can be less related to the key. The subdominant chord (e.g., the f-major chord in the key of c) which has a less important tonal function is used less often at the end of a sequence and thus has less expectancy. In the Musical Priming Paradigm, a priming chord sequence is followed by a target chord which has either a tonic or subdominant tonal function within the harmonic sequence. Studies have shown that with a harmonic sequence of chords, a highly related (i.e., expected, tonic) final chord is processed faster than a less related chord (i.e., unexpected, subdominant); this is known as Tonal Expectancy Formation (TEF). In the musical priming paradigm, the tonal function effect has been shown with various experimental tasks that assessed the speeded processing of a perceptual feature of the target chord, such as its timbre. For example, Tillmann et al. (2006) found that participants were able to identify the timbre of the final chord in a sequence faster and more accurately when the sequence ended in a tonic chord compared to a subdominant chord.

Hoch and Tillman (2010) combined the dichotic listening paradigm and musical priming paradigm to investigate hemispheric specialization for verbal and musical structure processing. Participants listened to a dichotic pair which consisted of a musical chord sequence and a verbal syllable sequence presented simultaneously to opposite ears. The musical sequences consisted of 7 chords played with one timbre, and the eighth target chord was played with either of two timbres. The target chord was either tonic or subdominant in relation to the priming sequence. In the opposite ear, the verbal stimuli consisted of 7 spoken syllables with the eighth target syllable either /di/ or /du/ A right or left arrow appeared 240 ms after target onset while the target was still playing to cue participants which ear/task they were supposed to attend/perform on a given trial. In other words, they determined either the final syllable or the final timbre of the paired sequence depending on which sequence was presented to the cued ear on a given trial.

As mentioned above, the contralateral processing pathway involves the crossing over of auditory stimuli to the opposite hemisphere of the brain from the ear of presentation. Hoch and Tillman (2010) reasoned that performance on both the music and verbal tasks would be optimal when the respective stimuli were being sent to the hemispheres specialized to process them. This condition would allow for stimuli to be processed the fastest and reduce the interference occurring due to the cross-over of stimuli to the opposite hemisphere. Hoch and Tillman (2010) reasoned that the tonal function effect would only occur when music was being processed optimally: participants would perform the timbre task faster and more accurately when the final chord was tonic rather than subdominant; but only when music was presented to the hemisphere specialized to process music. According to this rational, Hoch and Tillman (2010) interpreted a three-way interaction of Task (music or verbal) by Tonal Function (tonic or subdominant) by Ear of Music Presentation (EMP; left or right) as evidence for right hemisphere lateralization for music processing. Specifically they found that in the syllable identification task, the effect of tonal function was modulated by EMP such that response time in the timbre task was shorter when the final chord was tonic compared to subdominant only when music was presented to the left ear and thus processed primarily by the right hemisphere. Conversely, response times were faster for the syllable task when presented to the right ear than when presented to left ear suggesting a left hemisphere specialization for language processing.

The ultimate goal of the present line of research was to use Electroencephalography (EEG) recording to further investigate the right hemispheric specialization for music found by Hoch and Tillman (2010). Use of EEG would allow for a physiological measure of hemispheric signaling to strengthen and clarify laterality interpretations of the previous behavioral study. Nevertheless, is was first necessary to address a few issues with the Hoch and Tillman (2010) study in a behavioral study to ensure that their interpretations were reasonable.

While Hoch and Tillman (2010) arranged their response keys vertically (i.e. top to bottom: /di/, /du/, A, B), they did not address whether the spactial orientations of the keys would modulate performance on each of the verbal and timbre tasks. For example, Hoch and Tillman (2010) did not counterbalance the orientation of the response keys such that the keys for responding to the verbal task were always on top and keys for responding to the music task were on the bottom of the vertical arrangement. Likewise, iff the response keys are aligned on the right and music is presented to the right ear, the response key alignment can be said to be coherent with the ear of music presentation. On the other hand, for the key alignment directly above, if music is presented to the left ear and the verbal sequence is presented to the right, then the respective response keys and ear of stimuli presentation are said to be non-coherent (e.g., Figure 1).

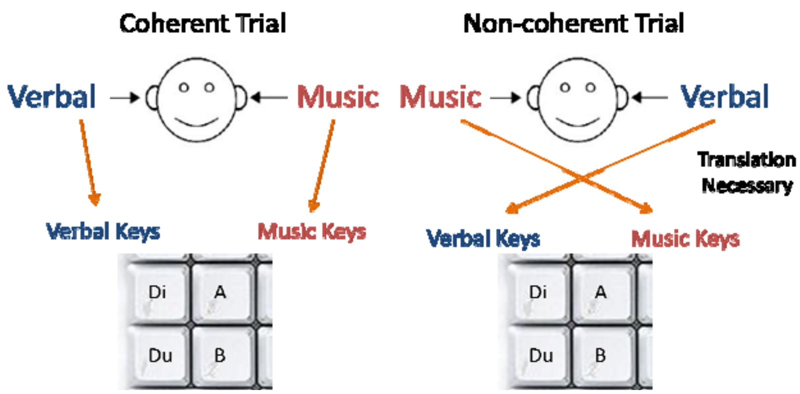

Figure 1. Coherence Effect of Response Key and EMP

Following from this one hypothesis of this study was that the orientation of the keys would affect task performance, as non-coherent trials require translation and may produce interference, resulting in a lower accuracy and longer response times.

A second factor that might mediate the behavioral task performance is response hand. Hoch and Tillman (2010) instructed participants to start the experiment using one hand to respond and then to change hands halfway through trials as a counterbalance, but did not include response hand as a within-subjects variable in their analysis nor did they report that there was no effect due to response hand. Through the contralateral processing pathway, each hand is controlled by the opposite hemisphere, (i.e., the left hand is controlled by the right hemisphere and the right hand is controlled by the left hemisphere). Similar to the Coherence Effect described for response key orientation and ear of music presentation, there is also a possible coherence effect of response key orientation and response hand that could influence task performance. In the key orientation shown in Figure 2, a coherent trial involves performing the timbre task while responding with the right hand; an incoherent trial would be performing the timbre task while responding with the left hand. The hypothesis of this study was that the response hand used would affect task performance, as non-coherent trials require translation and may produce interference, resulting in a lower accuracy and longer response times.

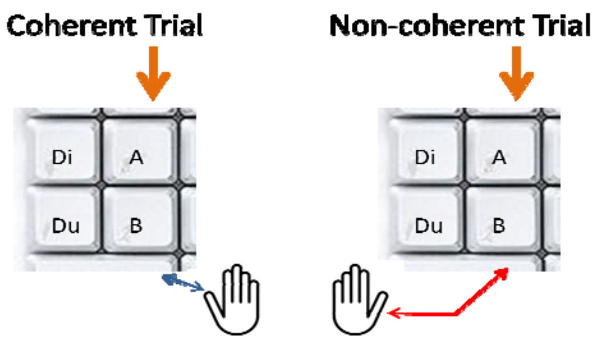

Figure 2. Coherence Effect of response key orientation and response hand

Finally, Hoch and Tillman (2010) presented the cue 240 ms after target onset to encourage participants to listen to both sequences. It was reasoned that this type of presentation would encourage participants to listen to both channels and thus be necessary in order for the two auditory channels to compete for the target events. A third question addressed in the current study was whether having the cue appear before the end of the target note was necessary for this competition to occur, or if the same partial interference of channels would occur if the cue appeared after the end and not during the target event.

Experiment 1

Method

Participants

45 right-handed non-musician undergraduate students of Union College in Schenectady, NY (9 male and 36 female) participated in the 45 minute testing session for either psychology course credit or $6.

Materials

*Speech Sequences***.** Each of the 12 sequences contained eight spoken consonant–vowel syllables. The first seven syllables were selected from a pool of consonant–vowel syllables commonly used in the English language, and the eighth syllable (the target) was /di/ or /du/ which provided 24 speech sequences. Each of the first seven syllables sounded for 625ms and the eighth target syllable sounded for 850ms including resonance. The inter-syllable interval was 0 ms .

Musical sequences. Each of the 12 musical sequences covered one of the 12 major keys and contained eight chords. The first seven chords defined the context. The eighth chord (the target) functioned either as a tonic or as a subdominant chord, and each sequence included an instance of both types of targets, resulting in 24 musical sequences. The 24 chord sequences were played by the trumpet and the target in one sequence by a grand piano sound (referred to as Timbre A) or in another sequence by a guitar sound (Timbre B), resulting in 48 sequences. Each context chord sounded for 625ms and the target sounded for 850ms including resonance. The inter-chord interval was 0 ms.

Dichotic pairs. A dichotic pair consisted of the simultaneous presentation of one speech sequence to one ear and one musical sequence to the contralateral ear, so that each syllable's onset was synchronized with each chord's onset. The 24 speech sequences (i.e., with the final syllable being /di/ or /du/) were paired with the 24 musical sequences (i.e., with the final timbre being A or B) that ended on a tonic and with the 24 musical sequences that ended on a subdominant chord, resulting in 48 dichotic pairs. Within this set, half of the timbre sequences were paired with a speech sequence ending on /di/, and the other half were presented with a speech sequence ending on /du/ (equally for left/right ear and for tonal function). This was counterbalanced for each target timbre as well as across participants.

Each dichotic pair was repeated twice: The musical sequence was presented once to the left ear and once to the right ear, resulting in 96 trials.

Musical sequences were constructed with Garageband software on an Apple and the consonant–vowel syllables were spoken by a synthetic voice from Test Vocal software. All stimuli in Experiment 1 where presented with the Neuroscan Stim2 software.

Procedure

The experimental trials were preceded by practice trials, resulting in a testing session of 45 min. In the practice session, participants heard examples of each target syllable (i.e., /di/, /du/) and target timbre (i.e., Timbre A, Timbre B), as well as complete speech and musical sequences. First, they were trained with feedback to differentiate between the two timbres (i.e., Timbre A, Timbre B), with 48 single chords and six eight-chord sequences presented binaurally. They were asked to identify, as quickly and accurately as possible, whether the target (the single chord or the final chord of the sequences) was played with Timbre A or Timbre B. Participants were then trained to distinguish between the spoken syllables /di/ and /du/ with 24 single syllables and six eight-syllable sequences presented binaurally. They were asked to identify, as quickly and accurately as possible, whether the target (the single syllable or final syllable of the sequence) was /di/ or /du/. Finally, participants were trained with eight dichotic pairs. For the dichotic pair task, participants were asked to listen to both speech and musical sequences and to watch the screen for an arrow that cued them to which task/ear they were supposed to respond. For each trial, their task was either to identify the final syllable (/di/ or /du/) or the timbre of the final chord (Timbre A or Timbre B) as quickly and accurately as possible. The musical sequence was randomly presented to the left or right ear (i.e., defining the factor “ear of music presentation”), and the speech sequence was simultaneously presented to the contralateral ear. The task-relevant ear, which changed randomly from trial to trial, was indicated by a visual cue that consisted of an arrow pointing to the left or right of the screen. For example, if the arrow pointed to the left, participants were instructed to respond to the material they heard in the left ear (syllable or timbre identification). In Experiment 1 this cue appeared directly after the end of the final 850ms event which was different than the original Hoch and Tillman (2010) to investigate if the cue must necessarily be presented before the end of the final event in order for the two channels to complete. In the experimental session, 96 dichotic pairs were presented in random order for each participant, and the task was the same as described for the dichotic pair practice session. For half of the participants, the response keys were aligned with A and B aligned vertically on the left and /di/ and /du/ aligned vertically on the right (Key Orientation 1); the other half of participants had the reverse key orientation, with /di/ and /du/ aligned on the right and A and B on the left (Key Orientation 2). Response hand was varied in the same manner as in the Hoch and Tillman (2010) study, i.e. half of the participants responded with the right index finger for the first half of the trials and with the left index finger for the second half, and the other half of the participants responded with the reversed finger assignment.

While listening to the dichotic pair, participants were asked to keep their index finger in the middle of the four response keys. Each response was followed by a 250-ms noise mask presented binaurally. There were two separate programs for the first and second half of the trials and participants were permitted to take a break between programs as well as additional short breaks between trials. The stimuli were presented using Stim2 behavioral analysis software, and accuracy and response time (RT) were recorded for each trial.

Results

The percent of correct responses (i.e., accuracy) for each participant and response times for all correct responses were analyzed in two separate 2 x 2 x 2 x 2 analyses of variance, with task (syllable identification, timbre identification), ear of music presentation (left ear, right ear), tonal function (tonic, subdominant), and response hand as within participant factors, and differential key orientation (Key Orientation 1, Key Orientation 2) as the between-participants factor.

There was a two-way interaction of Key Orientation by Tonal Function in the analysis of accuracy. For Key Orientation 1 (music task response keys on the left), participants were more accurate when the final target note was tonic. Nevertheless, with Key Orientation 2 (verbal task response keys on the left) there was an opposite effect- participants were more accurate when the final target note was subdominant (Figure 3).

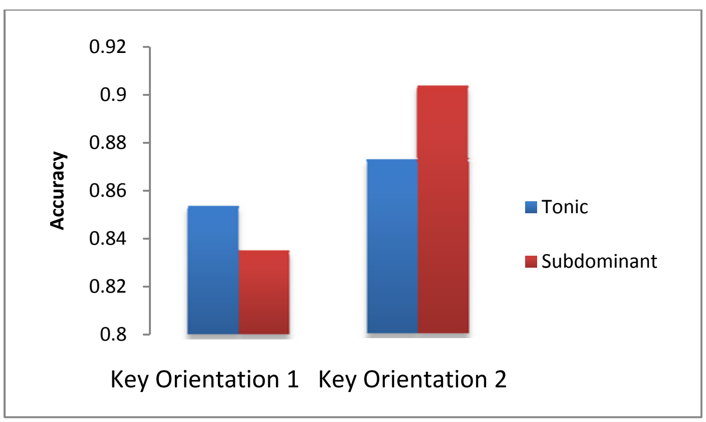

Figure 3. Key Orientation by Tonal Function for Percentage Correct Responses

There was also a two-way interaction of Key Orientation by Ear of Music Presentation (EMP) for both the accuracy and RT analyses. For Key Orientation 1, participants had a greater accuracy and faster RTs when music was presented to the right ear, and for Key Orientation 2 this occurred when music was presented to the left ear (see Figure 4).

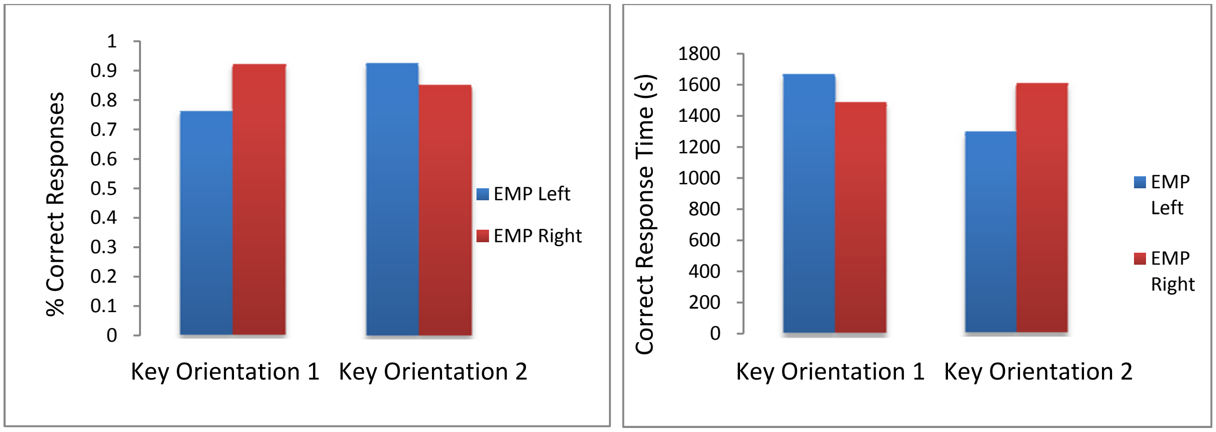

Figure 4. Key Orientation by Ear of Music Presentation for Percentage Correct Responses and Response Time

Discussion

For Key Orientation 1, the observed influence of tonal function (i.e. more accurate processing when the musical sequence ended in a tonic chord) is in agreement with musical priming effects reported in previous studies using the musical priming paradigm. Interestingly, however, this priming effect is not seen with Key Orientation 2; participants using Key Orientation 2 were more accurate when the final target note was subdominant. This result suggests that the alternative key orientation somehow modulates the tonal function effect of the target event. This modulation may be a result of an interference occurring when the hemisphere primarily processing a stimulus is non-coherent with the internal spatial representation of the corresponding response keys. For Key Orientation 1, the music response keys are on the right, and can be thought to have an internal visual representation in the right hemi-field. As it is hypothesized that music is primarily processed in the right hemisphere, for Key Orientation 1 the specialized hemisphere and the visual representation hemi-field are in congruence, and the musical priming effect occurs. For Key Orientation 2, on the other hand, the music response keys are on the left, and can be thought to have an internal visual representation in the left hemi-field.

In this instance, the specialized hemisphere (right hemisphere) and the visual representation hemi-field (left hemi-field) are not in congruence, and the expected musical priming effect does not occur. In Experiment 1 the cue appeared after the target note ended, so the timbre and syllable tasks were performed when the stimuli were in short term memory. When performing the task from short term memory, the tonal function effect occurs when the hemi-field of the music response key is on the same side as the hemisphere processing music. For example, the tonal function effect occurs for Key Orientation 1 in which the music response keys are represented in the right hemi-field and music is being processed in the right hemisphere. When performing the task from short term memory, the visual representation of the response keys has been processed and the hemi-field of this image coheres with the processing hemisphere so no translation is needed and the tonal function effect occurs.

The two-way interaction for Key Orientation by EMP suggest that Key Orientation modulates the effect of ear of music presentation. This interaction corresponds with the Task Ear- Response Key Coherence Effect. For Key Orientation 1, shown in Figure 5, participants are most accurate when music is presented to the right ear and thus verbal to the left ear because the task ear is in coherence with the response key orientation. In this instance, the music response keys are internally represented in the right visual hemi-field and music is being presented to the right ear; therefore, visual representation hemi-field and EMP are coherent, and there is no interference occurring resulting in increased accuracy. When music is presented to the left ear, the task ear is not in coherence with the response key orientation, and participants are less accurate. In this instance, the music response keys are internally represented in the left visual hemi-field and music is being presented to the right ear; therefore, visual representation hemi-field and EMP are not coherent and interference occurs which results in decreased accuracy. The opposite pattern is true for Key Orientation 2, as one would expect when the key orientation, and thus the coherence orientation, is reversed. Participants are most accurate when music is presented to the left ear and thus verbal to the right ear because the task ear is in coherence with the response key orientation, and thus the visual representation hemi-field and EMP are coherent. When music is presented to the right ear, the EMP is not in coherence with the response key orientation and thus visual representation hemi-field, and participants are less accurate.

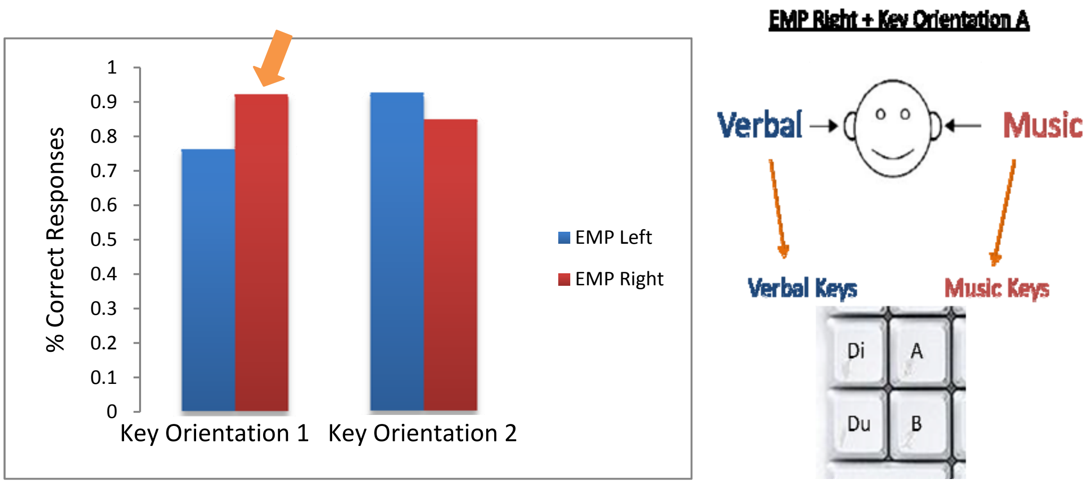

Figure 5. Coherence Effect demonstrated by Key Orientation by EMP for Percent Correct Responses

As both the cue presentation timing and response key orientation differ in Experiment 1 compared to Hoch and Tillman's study, the results of Experiment 1 cannot be definitively attributed to either factor individually. A desire to identify which variable accounts for the interactions found in Experiment 1 motivated Experiment 2. In Experiment 2, the only variation from the procedure of Experiment 1 was presentation of the cue 240ms after onset of the target event as opposed to after completion of the 850ms target event. As this cue placement is the same as Hoch and Tillman (2010), significant interactions in Experiment 2 can be attributed to the alternative response key orientation factor.

Experiment 2

Method

Participants

23 right-handed non-musician undergraduate students of Union College in Schenectady, NY (8 male and 15 female) participated in the 45 minute testing session for either psychology course credit or $6.

Materials & Procedure

The materials and procedure were the same as those described in Experiment 1, with the exception of presentation of the cue 240 ms after onset of the target event. Experiment 2 stimuli were presented with E-prime software.

Results

Two separate 2 x 2 x 2 x 2 analysis of variance were performed for accuracy and RTs using the same within-subject and between-subject variables as Experiment 1 (See Experiment 1 Results). For theaccuracy analysis there was a two-way interaction of Key Orientation by Tonal Function. Although the interaction was also found in Experiment 1, the direction of the effect differed between the two experiments, such that for Key Orientation 1 in Experiment 1, participants were more accurate when the final note was tonic, but in this condition in Experiment 2 participants were more accurate when the final note was subdominant (Figure 6). For Key Orientation 2 in Experiment 1, participants were more accurate when the final note was subdominant, but in this condition in Experiment 2 participants were more accurate when the final note was tonic.

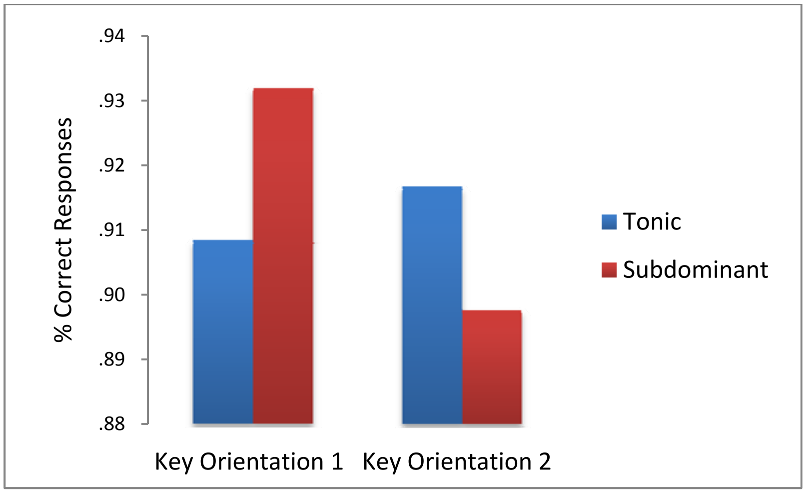

Figure 6. Key Orientation by Tonal Function for Percent Correct responses

A a two-way interaction of Key Orientation by Ear of Music Presentation (EMP) for both accuracy and RTs was found that was similar to that in Experiment 1. For Key Orientation 1, participants exhibited greater accuracy and faster response times when music was presented to the right ear, and for Key Orientation 2 this occurred when music was presented to the left ear (Figure 7).

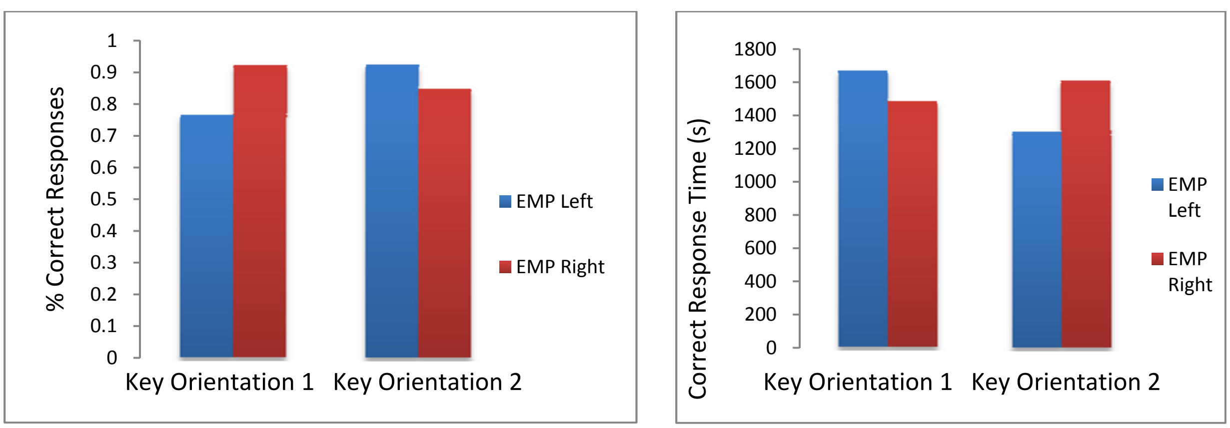

Figure 7. Key Orientation by Ear of Music Presentation for Percent Correct Responses and Response Time

There was a two-way interaction for accuracy between Response Hand and Tonal Function such that when participants responded with their left hand, they were more accurate on trials ending in tonic chords than subdominant chords. Conversely, when they used their right hand, they responded more accurately for subdominant chord trials (Figure 8).

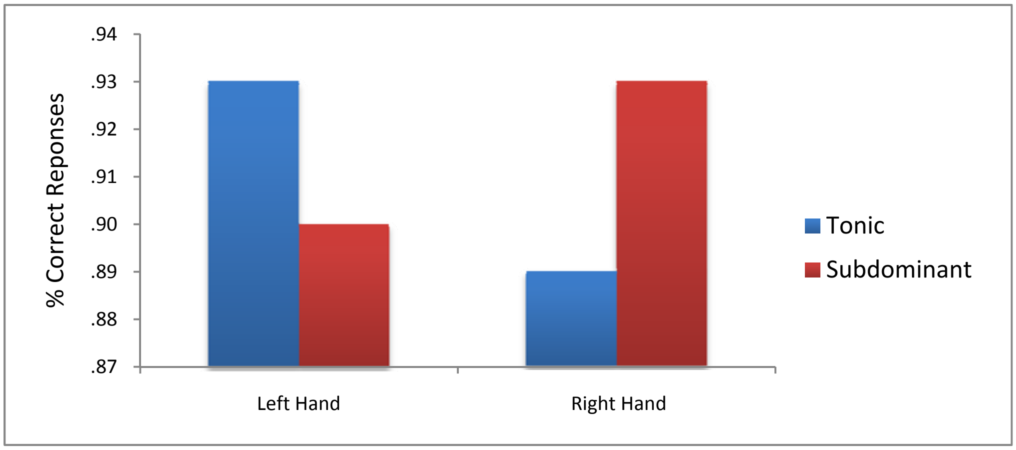

Figure 8. Response Hand by Tonal Function for Percentage Correct Responses

In addition, there was a three-way interaction between Key Orientation, Response Hand, and Task. For Key Orientation 1, participants were more accurate for the verbal task regardless of which hand was used to respond. For Key orientation 2, participants were also more accurate for the verbal task when responding with their right hand; interestingly, however, participants were more accurate for the timbre task when responding with their left hand.

Finally, there was a three-way interaction between Key Orientation, Response Hand, and Task for RTs. For Key Orientation 1, participants had the shortest RTs for the verbal task when using their left hand, and the shortest RTs for the music task when using their right hand. Conversely, for Key Orientation 2, participants had the shortest RTs for the verbal task when using their right hand, and the shortest RTs for the music task when using their left hand (Figure 9).

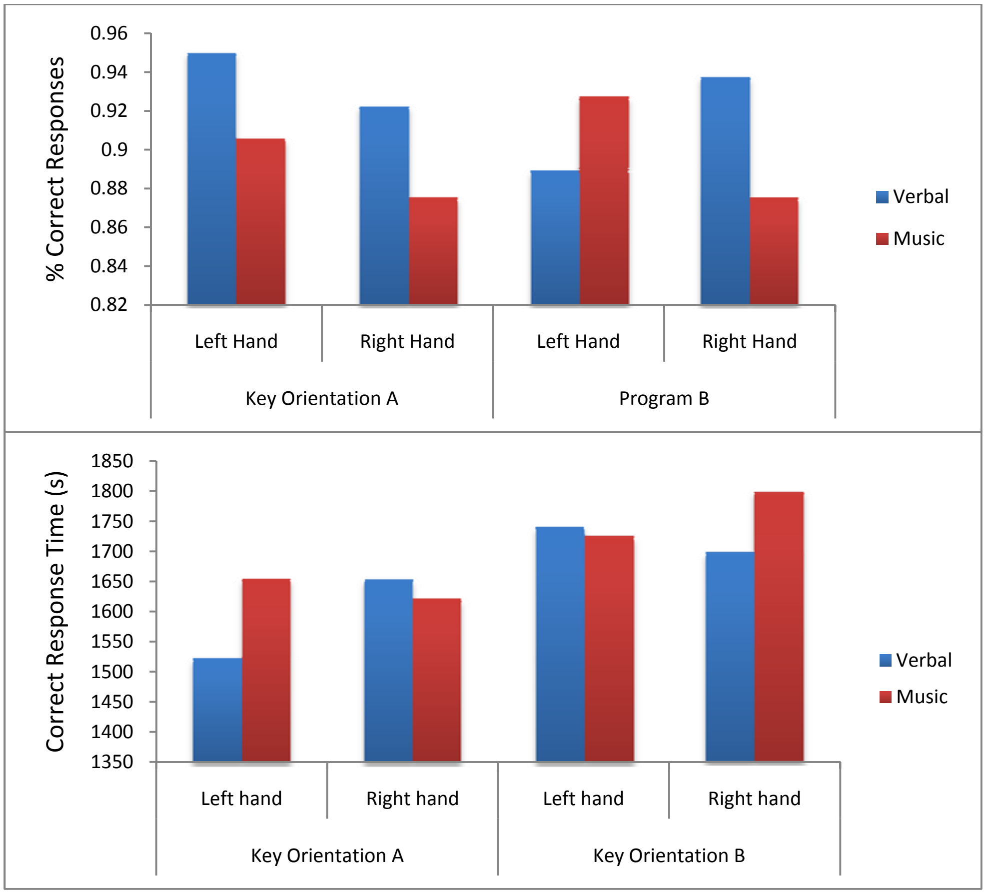

Figure 9. Key Orientation by Response Hand by Task for Percentage Correct Response and Response Time

Discussion

For Key Orientation 2, the observed influence of tonal function (i.e. more accurate processing when the musical sequence ended in a tonic chord) is in agreement with musical priming effects reported in previous studies using the musical priming paradigm. Interestingly, however, this priming effect is not seen with Key Orientation 1; participants using Key Orientation 1 achieve accuracy when the final target note is subdominant. The alternative key orientation somehow modulates the tonal function effect of the target event. This modulation may be a result of an interference occurring when the hemisphere primarily processing a stimulus is non-coherent with the internal visual representation of the corresponding response keys. In Experiment 2 the cue appeared while the target note was still playing, so the timbre and syllable tasks were performed when the stimuli were in sensory memory. When performing the task from sensory memory, the tonal function effect occurs when the hemi-field of the music response key is opposite to the hemisphere processing music. For example, the tonal function effect occurs for Key Orientation 2 in which the music response keys are represented in the left hemi-field while music is being processed in the right hemisphere. It is possible that when performing the task from sensory memory (Experiment 2), the visual representation of the response keys is sent to the hemisphere opposite to the image's hemi-field through a contralateral processing pathway. In the example previously cited, the left hemi-field representation of the response keys is sent to the right hemisphere for processing; thus, the musical stimuli and the music response key representation are processed in the same hemisphere so no translation is needed and the tonal function effect occurs.

The two-way interaction of Key Orientation by Ear of Music Presentation (EMP) for both percentage of correct responses and correct response time corresponds with the Task Ear-Response Key Coherence Effect. For example, for Key Orientation 1 (shown in Figure 10) participants are most accurate when music is presented to the right ear and thus verbal to the left ear because the task ear is in coherence with the response key orientation. In this instance, the music response keys are internally represented in the right visual hemi-field and music is being presented to the right ear; therefore, visual representation hemi-field and EMP are coherent, and there is no interference occurring resulting in increased accuracy. When music is presented to the left ear, the task ear is not in coherence with the response key orientation, and participants are less accurate. In this instance, the music response keys are internally represented in the left visual hemi-field and music is being presented to the right ear; therefore, visual representation hemi-field and EMP are not coherent and interference occurs which results in decreased accuracy. The opposite pattern is true for Key Orientation 2, as one would expect when the key orientation, and thus the coherence orientation, is reversed. Participants are most accurate when music is presented to the left ear and thus verbal to the right ear because the task ear is in coherence with the response key orientation, and thus the visual representation hemi-field and EMP are coherent. When music is presented to the right ear, the EMP is not in coherence with the response key orientation and thus visual representation hemi-field, and participants are less accurate.

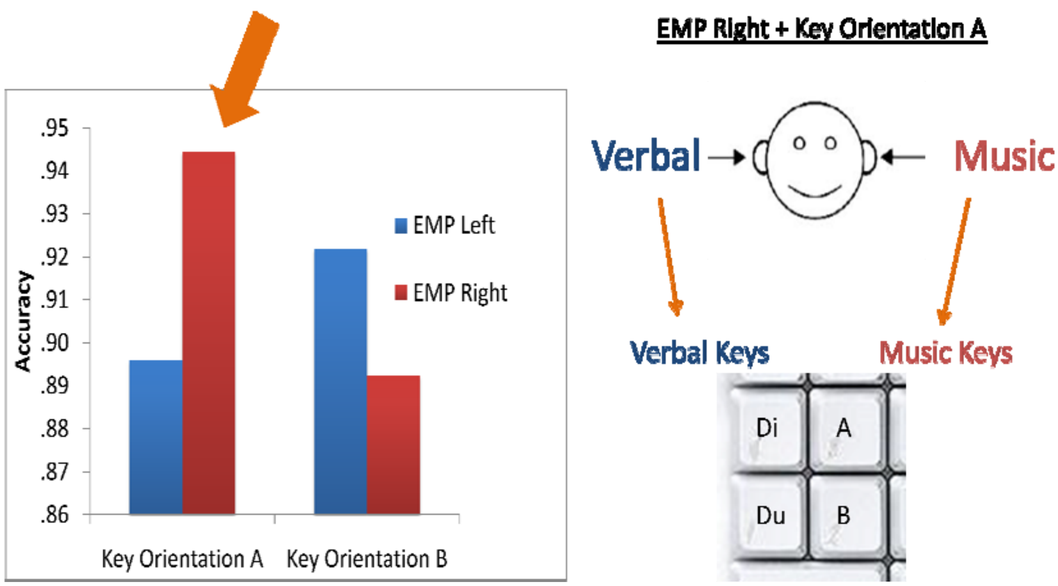

Figure 10. Coherence Effect demonstrated by Key Orientation by EMP for Percent Correct Responses

The two-way interaction between Response Hand and Tonal Function for accuracy shows that response hand used modulates the effect of the musical priming paradigm. The predicted tonal function effect (i.e. better accuracy for tonic chord trials) occurred when participants used their left hand. Since the left hand is controlled by the right hemisphere and music is hypothesized to be specially processed in the right hemisphere, the tonal function effect occurs when the hemisphere controlling the response hand is congruent with the hemisphere processing music. Conversely, when the right hand (left hemisphere) is noncongruent with the hemisphere specialized to process music (right hemisphere), the tonal function effect does not occur. If music is processed in the right hemisphere, it is possible that it the translation to the opposite hemisphere in order to control left hand movement interferes with the proper processing of the music. The expected tonal function effect occurs when processing and control of hand movement is localized to the same hemisphere, and thus this translation is not necessary. While Hoch and Tillman (2010) claimed that tonic chords would result in better accuracy, they did not account for the possible translational interference that switching response hand half-way through trials would have on accuracy. This interaction from Experiment 2 suggests that one cannot make assumptions about the musical priming effect of tonal function without analyzing the translational effect of response hand.

In addition, there was a three-way interaction between Key Orientation, Response Hand, and Task. For Key Orientation 1, participants had greater accuracy for the verbal task regardless of which hand was used to respond. This finding corresponds with Hoch and Tillman (2010), as they found that participants responded correctly more often for the verbal task than the timbre task. For Key Orientation 2, however, there was no effect of task: participants were responded more accurately for the timbre task when using their left hand to respond. This 3-way interaction between Key Orientation, Response Hand, and Task was also found for RTs. For each respective Key Orientation, the condition for which participants had the shortest correct response time for each respective task indicate a possible Coherence Effect involving an interaction of response key orientation, response hand used, and task performed. For example, for Key Orientation 1, participants had the shortest response times for the verbal task when using their left hand, and the shortest response times for the music task when using their right hand. Conversely, for Key Orientation 2, participants had the shortest response times for the verbal task when using their right hand, and the shortest response times for the music task when using their left hand. These four conditions are shown in Figure 11, in which you can see that each condition is a coherent trial (i.e. the response hand used is in coherence with the response keys necessary to complete the cued task). In each coherent trial, the hemi-field in which the response key is visually represented is in coherence with the hand being used to respond. For Key Orientation 1, for example, the verbal response keys are represented in the left hemi-field, and participants are more accurate when responding with their left hand.

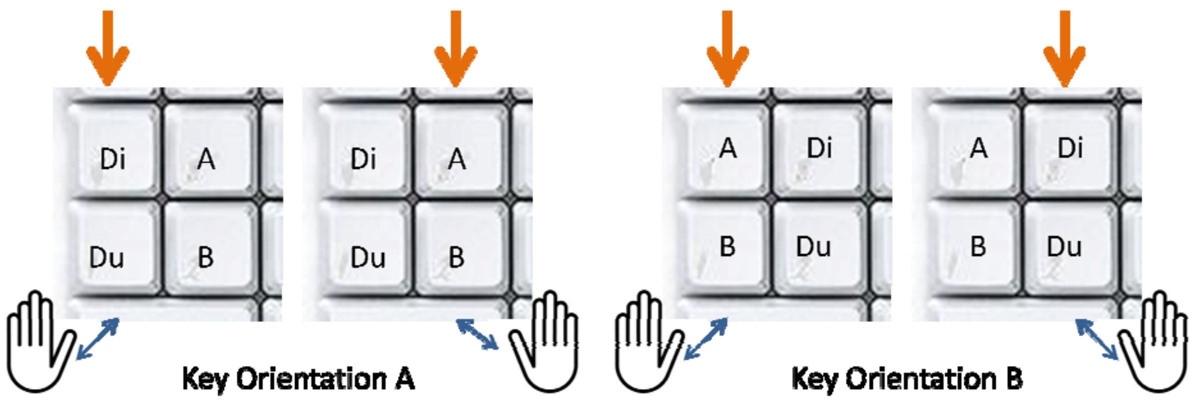

Figure 11. Shortest correct response times were all coherent trials

For each of these key-orientation and task conditions, the use of the opposite hand to respond resulted in the longest correct response times (shown in Figure 12). These conditions are all non-coherent trials, i.e. the response hand used is not in coherence with the response keys necessary to complete the cued task. Converse to the coherent trials previously described, in each non-coherent trial the hemi-field in which the response key is visually represented is in not in coherence with the response hand. For Key Orientation 1, for example, the music response keys are represented in the right hemi-field, and participants are more accurate when responding with their left hand.

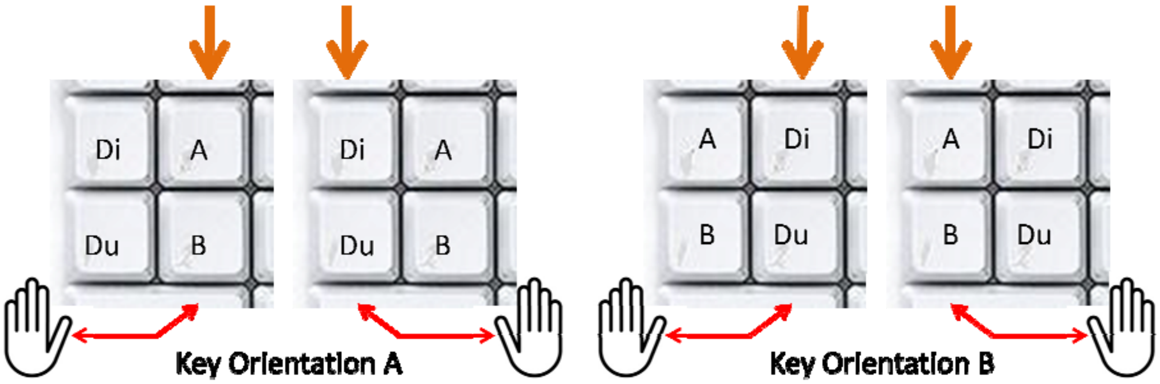

Figure 12. Longest correct response times were all non-coherent trials

This interaction suggests that performance is optimal when the internal visual representation of the response keys does not need translation to the hand opposite the hemi-field in which it is represented. The two interactions found between Key Orientation, Response Hand, and Task further indicate that both key orientation and response hand significantly affect task performance. Their effects also interact with each other in accordance with the Coherence Effect possibly due to translation of the visual representation of the response keys.

General Discussion

While the same 2-way interaction of Key Orientation by Tonal Function was found in both Experiment 1 and Experiment 2, the nature of the effect that key orientation on accuracy differed between the two experiments. Since the only difference between Experiment 1 and Experiment 2 was the placement of the cue, the comparison of these interactions suggests that the type of memory being accessed affects task performance. In Experiment 1, the participant accessed short term memory, and the tonal function effect occurred when the hemi-field of the response key representation was in coherence with the right hemisphere; In Experiment 2, on the other hand, the participant accessed sensory memory, and the tonal function effect occurred when the hemisphere processing the response key representation was in coherence with the right hemisphere. This difference may be a result of the nature of the internal visual representation, as when working with sensory memory the interference occurs when the stimuli and the response keys are being processed simultaneously in opposite hemispheres.

Since the two-way interaction of Key Orientation by Ear of Music Presentation (EMP) for both percentage of correct responses and correct response time was found for both Experiment 1 and Experiment 2, this suggests that this interaction is a result of the response key orientation factor. The results of both experiments tell us that the effect of ear of music presentation is modulated by the response key orientation, and that this modulation is most likely associated with the Coherence Effect of the task ear and response keys. It was determined that both response hand used and response key orientation effect task performance. Also, both variables modulate the effects of ear of music presentation and tonal function on task performance.

Hoch and Tillman (2010) interpreted their results to support a very specific laterality effect; the results of this behavioral study show that there are many more variables that affect performance on this dichotic listening task. The current study showed that alternative key orientations affect task accuracy, possibly due to hemispheric interference involving the processing of response keys in respective hemi-fields of internal representation. It is possible that the alternative key orientation used by Hoch and Tillman (2010) (i.e. vertical alignment of the response keys) may have affected the results in a similar way. While the response key orientation differed between the Hoch and Tillman (2010) study and the current study, the response hand variable was the same in the two studies. Since inclusion of the response hand variable in the statistical analysis in the current study resulted in significant interactions involving response hand, it is clear that response hand used effects task performance. Without including response hand as a within-subjects variable, Hoch and Tillman (2010) cannot reliably interpret their results to indicate the presence of a laterality effect.

Future steps in this laterality study would include the addition of the response key orientation used by Hoch and Tillman (2010) (i.e. from top to bottom, /di/, /du/. A, B) as well as more possible key orientations (i.e top to bottom A, B, /di/, /du/) to further investigate if the specific response key orientation used by Hoch and Tillman (2010) influenced their results. While the two key orientations used in the current study have clear hemi-field representations, the vertical alignment of the response keys may cause translational interference in a similar manner. In order to further investigate the interactions involving response hand in the current study, more participants should be run and added to the analysis, and the analysis should be done without the key orientation variable for more statistical power. These additional participants and analysis as well as the additional response key orientations may provide evidence that Hoch and Tillman (2010) would not have found their reported results if they had included response hand and key orientation variables in their analysis of variance. The addition of EEG recording to the current study may further reveal what hemispheric specializations, if any, are involved in the processing of verbal and musical stimuli.

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