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HEMISPHERIC ASYMMETRIES IN MUSICIANS AND NONMUSICIANS FOR MATCHING VISUAL METAPHORS TO SOUND

by

Jeffrey Howard Sugarman

B.A., University of Waterloo, 1979

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
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ABSTRACT

A forced-attention, dichotic listening task based on Walker's (1987) cross-modal matching paradigm was administered to 40 right-handed voluntary male university students, half of whom were musicians, and the other half, nonmusicians. Walker has reported that changes in acoustic parameters are cross modally represented along specific dimensions in the visual modality, and subjects will consistently match appropriate visual metaphors to sounds. The target stimuli were three-second sound segments which varied in one of four discrete acoustical parameters: frequency, waveform, duration, or amplitude. The competing stimuli were random pure tones generated at 22 tones per second, simulating noise. For each dichotic pair of auditory stimuli, subjects chose a visual metaphor. The results show a right-ear advantage for musicians and a left-ear advantage for nonmusicians. Musical training accounted for 40% of the variance on right-ear error scores as opposed to 7% on left-ear error scores. There were no significant differences in subjects' patterns of asymmetry between the four acoustical parameters manipulated in the stimuli. The results were interpreted as demonstrating that musicians possess left-hemisphere cognitive structures which permit more efficient processing of sounds. It is proposed that accessibility to such domain specific structures is a major determinant of hemispheric asymmetries.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Introduction

The focus of this study is an investigation of the degree to which education and experience can influence differential hemispheric asymmetries. The domain of investigation is the discrimination of change in fundamental acoustic parameters, and formal education and experience in music. A cross-modal matching paradigm (Walker, 1987), in which subjects match visual metaphors to auditory stimuli, is employed as the dependent measure.

This research addresses three questions. First, to what extent does musical training and experience influence hemispheric asymmetries for the discrimination of fundamental acoustic parameters in processing auditory stimuli? Second, to what extent are hemispheric asymmetries invoked by the specific fundamental acoustic parameter represented in the auditory stimulus? Third, to what extent are differences in hemispheric activation dependent upon the amodal or modal-specific nature of the acoustical component being manipulated?

It is hoped that, through a synthesis of knowledge and procedures acquired from neuropsychology and cognitive science, this study will provide evidence to further explicate the relationship between cognitive functions and cerebral asymmetries.

Overview of the Literature Review

The literature review is presented in four sections. The first section serves to establish a theoretical framework within which to view the empirical evidence pertaining to hemispheric asymmetries. The second section examines theoretical and methodological considerations relevant to the dichotic listening procedure. The third section addresses the empirical research aimed at discerning differences in lateral asymmetries between musically trained and untrained subjects. The fourth section applies Walker's (1987) cross-modal matching paradigm and investigates its utility for differential lateral asymmetries accruing from musical training.

Cerebral Lateralization

Over the last three decades, attempts to explain cognitive processes in terms of underlying cerebral asymmetries has yielded a venerable body of empirical and theoretical literature. Traditionally, left and right hemispheric functions have been interpreted as being elicited by respectively, the verbal and nonverbal nature of the stimulus (Kimura, 1964). According to Kimura's model, lateral functions are viewed for the most part as passive and stimulus determined. With mounting contradictory evidence, the verbal/nonverbal dichotomy was supplanted by the notion that each hemisphere maintained its own characteristic style of information processing: the left being "logical" and the right being "synthetic" (Levy-Agresti & Sperry, 1968); the left being "propositional" and the right being "appositional" (Bogen, 1969); or the more current and broadly accepted distinction, the left being "analytic" and the right being "holistic" (Bradshaw & Nettleton, 1981). The emphasis shifted to strategy, which reflected the hemispheric mode actively adopted by the individual. While there has been much debate over the utility of functional dichotomies (see Bradshaw & Nettleton, 1981 and open peer commentaries), Cook (1986) has pointed out the consistent depiction of high-level complementarity and that the nature of the neural mechanism necessitates broad generality in determining a functional as opposed to a merely descriptive, dichotomous taxonomy of cerebral functions.

Morais (1980; cited in Bertelson, 1981) has asserted the need to integrate neuropsychological evidence with concurrent advances in cognitive psychology to further elucidate hemispheric functions. In attempting to explicate a functional relationship between the hemispheres some investigators have employed the construct of descriptive systems, which refers to algorithmic configurations of elementary feature detection mechanisms (Goldberg & Costa, 1981; Goldberg, Vaughan, & Gerstman, 1978). Descriptive systems such as schema are data structures which facilitate the representational and integrative processing of basic informational units (Rumelhart & Norman, 1985). Goldberg, et al. (1978) propose that the multiplicity of descriptive systems instrumental in cognitive operations can be conceptualized as belonging to one of two categories: those for which there are pre-existent codes and those for which no pre-existent codes have been established. Distinguishing these two types of codes is contingent upon the individual's extant knowledge and familiarity with the stimulus. While examples of pre-existent codes might include those of natural language, musical notation, or mathematics, the absence of pre-existent codes would be evident in the acquisition of a novel skill, such as learning to use a computer or perhaps musical training (Goldberg & Costa, 1981).

Goldberg and Costa (1981) suggest that without accessibility to an appropriate descriptive system, problem resolution becomes the unsystematic implementation of diverse encoding strategies. Productive components of various attempted strategies are subsequently reassembled into a new descriptive system. In such instances, a structure which is characteristically diffuse and permits increased access and combinatorial power to dissimilar, intermixed groupings of informational units would be advantageous. In contrast, a structure based on the fixed codes of extant descriptive systems would benefit from the increased accessibility afforded by focal, compact storage. As well, this view of functional and structural asymmetry is consistent with Semmes (1968) proposition of a diffuse representation of functions in the right hemisphere and a focal representation of functions in the left hemisphere. Goldberg and Costa purport that anatomical asymmetries such as an increased proportion of white to grey matter in the right hemisphere (Gur, Packer, Hungerbuhler, Reivich, Obrist, Amarnek, & Sackheim, 1980) is indicative of greater interregional neuronal organization in the right hemisphere in contrast to greater intraregional neuronal organization in the left hemisphere. A convergent notion is proffered by Woodward (1988), that long horizontal neuronal connections in the right hemisphere and more compact connections in the left hemisphere could subserve different memorial encoding strategies. A theory of dual encoding processes for memory which parallel these anatomical differences has been advanced by Hinton, McClelland, and Rumelhart (1986).

Sergent (1982) has proposed that there are asymmetries in the degree of sensory resolution applied to input information, but that these perceptual differences only emerge when cognitive operations are performed. According to Sergent, the hemispheres respond to different features of a stimulus and that different neural representations act to differentially limit hemispheric processing and predispositions. In light of Goldberg and Costa's (1981) theory, sensory resolution could largely be determined by accessibility to relevant descriptive systems and predisposition could be contingent on the existence or development of such systems.

Thus, it is posited that distinctive characteristics of right and left hemispheric cerebral organization facilitates the differential processing of novel and familiar stimuli respectively, and that hemispheric activation is determined on the basis of perceived task demands, and available, pre-existing descriptive systems accruing from prior knowledge. This is not to attribute exclusivity of function to a specific hemisphere but to suggest a high degree of complementarity such that each hemisphere might be better suited for processing specific characteristics of an event. Empirical support for this model is derived from studies finding a left-hemisphere advantage on tasks using familiar materials and a right-hemisphere advantage on novel tasks (e.g., Bartholomeus, 1974; Molofese, Freeman, & Palermo, 1975; Seamon & Gazzaniga, 1973; Denes & Spinaci, 1981).

Other convergent evidence is found in causal-comparative studies of "sophisticated" and "unsophisticated" subjects. For example, Papcun, Krashen, Terbeek, Remington, and Harshman (1974) found that trained Morse Code operators showed a left-hemisphere advantage compared to naive subjects who demonstrated a right-hemisphere advantage in recognizing Morse Code sequences of more than seven elements. A similar difference in the pattern of asymmetry has been reported with bilinguals learning a second language: a left-hemisphere advantage for native language stimuli and a right-hemisphere advantage for second language stimuli (Silverberg, Bentin, Gazier, Obler, & Albert, 1979; Silverberg, Gordon, Pollack, & Bentin, 1980). Goldberg et al. (1978) found a left-hemisphere advantage for shape-texture discriminations in individuals with backgrounds in visual arts. Both Bever and Chiarello (1974) and Johnson (1977) have reported left-hemisphere advantages for musicians and right-hemisphere advantages for nonmusicians. The relationship between lateral asymmetries and musical sophistication will be discussed at greater depth in a subsequent section. Also, the left-hemisphere advantage traditionally associated with verbal tasks might be reinterpreted as an artifact of a left-hemisphere disposition for existing descriptive systems developed in the acquisition of language. Concomitantly, the right-hemisphere advantage associated with nonverbal classes of stimuli could be engendered by the novel nature of many nonverbal types of tasks.

The evidence which has been presented would seem to suggest a right- to left-hemisphere shift with increased competence and familiarity. Right to left shifts in hemispheric advantage occurring temporally within tasks have been reported using a variety of stimuli and experimental paradigms (cf., Dee & Hannay, 1981; Gordon & Carmon, 1976; Halperin, Nachshon, & Carmon, 1973; Hannay, Dee, Burns & Masek, 1981; Hellige, 1976; Kittler, Turkewitz, & Goldberg, 1989; Perl & Haggard, 1975). Ross-Kossak and Turkewitz (1986) have reported right to left shifts in hemisphere advantage in studies of face recognition (e.g., Ross & Turkewitz, 1982; Ross-Kossak & Turkewitz, 1984). While these researchers also reported an additional shift back to a right-hemisphere advantage, this latter finding should be interpreted with caution as there has been failure to replicate the effect (Kittler et al., 1989).

Goldberg and Costa (1981) have also proposed that tasks become "routinized" to the left hemisphere with increasing familiarity. It has been shown that an initial left-hemisphere advantage can increase proportionately over a number of experimental sessions (Blumstein, Goodglass, & Tartter, 1975; Shankweiler & Studdert-Kennedy, 1975).

The Dichotic Listening Paradigm

The dichotic listening paradigm employs the simultaneous presentation of different auditory stimuli to each ear. Broadbent (1954) originally implemented the technique in studies of selective attention. However, the work of Kimura (1961a, 1961b) precipitated great interest in applying dichotic listening to the investigation of hemispheric asymmetries. The procedure is predicated on the notion that when presented with competing auditory stimuli, there is suppression of ipsilateral information traveling to the cortex and that information is more strongly represented in the contralateral hemisphere (Kimura, 1961a). While increased numbers of fibers and faster transmission speeds have been attributed to contralateral pathways (Majkowski, Bochenck, Bochenck, Knapik-Fijalkowska, & Kopec, 1971; Rosenzweig, 1951), there is some evidence of individual differences in the magnitude of ipsilateral suppression (Hellige & Wong, 1983; Sidtis, 1982; Teng, 1981). It has also been suggested that the magnitude of ipsilateral suppression increases as a function of the spectral and temporal similarity between target and competing stimuli (Berlin, Porter, Lowe-Bell, Berlin, Thompson, & Hughes, 1973; Springer, Sidtis, Wilson, & Gazzaniga, 1978).

Two models have been proposed to account for observed asymmetries on dichotic tasks (Bradshaw, Burden, & Nettleton, 1986). The direct access model asserts that dichotically presented material is directly processed by the contralateral hemisphere and that lateral asymmetries reflect differential hemispheric abilities. The callosal relay model holds that asymmetries result from either or both, signal degradation and the time added for callosal transmission to the hemisphere exclusively specialized to process the event. Umilta, Rizzolatti, Anzola, Luppino, and Porro (1985) have proposed a conditional model positing that each hemisphere is capable of processing input information. Under dichotic conditions, stimulus processing occurs in the contralateral hemisphere and variance in performance is indicative of differential hemispheric functions. However under normal conditions, the interhemispheric transmission time required to relay information across the corpus callosum to the hemisphere most suited for processing a specific event is responsible for lateral asymmetries.

The dichotic technique has proven to be a robust, noninvasive experimental procedure for demonstrating some lateral asymmetries (Bryden, 1982). Despite its utility, procedural variations have been shown to effect the direction and magnitude of asymmetries. Variations in attentional factors and subjects' report strategies (Bryden, 1978; Bryden, Munhall, & Allard, 1983; Freides, 1977), and stimulus and task factors (Bloch & Hellige, 1989; Berlin, 1977), have been observed in relation to differences in performance. Bryden (1982) suggests that an attentional monitoring procedure (e.g., Bryden et al., 1983) in which subjects monitor and report the items presented to one ear at a time in counterbalanced blocks of trials, helps to reduce the effects of extraneous strategy and attentional variables. However, it is hypothesized that lateral differences attributed to task and stimulus characteristics are a function of an individual's accessibility to existing descriptive systems, and the degree of ipsilateral suppression. Hence it is important to consider stimulus and task factors in relation to the subject.

Additionally, Kallman and Corballis (1975) have reported that an initial left-ear advantage can dissipate over time. Since then it has become common procedure to employ practise trials to compensate for such "practise effects" and to "familiarize" the subject with the task. The effects demonstrated on these initial practise trials are rarely reported and may well reflect a right-hemisphere advantage engendered by an incipient perceived novelty of the task.

Three other variables have been demonstrated to have a relationship to dichotic performance: handedness, family handedness background, and gender. Reversed and attenuated patterns of asymmetry have been reported for left-handed subjects (Dee, 1971; Piazza, 1980; Zurif & Bryden, 1969).

It has also been shown that a familial history of sinistrality can be related to a reduction or reversal of the normal pattern of asymmetry in right-handed individuals (Hines & Satz, 1971; Kellar & Bever, 1980; Lake & Bryden, 1976). While the evidence reported on gender differences has been inconsistent with respect to a variety of linguistic and nonlinguistic stimuli (Bryden, 1979; McGlone, 1980), with respect to "musical" stimuli Piazza (1980) reported greater left-ear advantages for women on a melody recognition task.

Differences Between Musicians and Nonmusicians

Dichotic procedures have been used extensively in the investigation of hemispheric asymmetries for the processing of musical stimuli (Gates & Bradshaw, 1977a). Comparative studies of musicians and nonmusicians have yielded mixed findings. Some investigators have reported a right-ear advantage for musicians and a left-ear advantage for nonmusicians (Johnson, 1977; Johnson, Bowers, Gamble, Lyons, Presbrey & Vetter, 1977; Wagner & Hannon, 1981). Others have reported a left-ear advantage for nonmusicians but no ear advantage for musicians (Morais, Peretz, Gudanski, & Guiard, 1982), and a right-ear advantage for musicians but no ear advantage for nonmusicians (Prior & Troup, 1988). There are also reports of ear advantages occurring in the opposite direction (Kellar & Bever,1980; Gates & Bradshaw, 1977b;

Gordon, 1970, 1978, 1980; Shanon, 1979), and findings of no ear advantages for either group (Prior & Troup, 1988; Shanon, 1981; Zatorre, 1979). Additionally, an often cited study by Bever and Chiarello (1974) found a left-ear advantage for musicians and a right-ear advantage for nonmusicians employing a monaural task.

Considering the inconsistent nature of the evidence, a number of experimental factors emerge. Given that musicians demonstrate greater accuracy in most types of musical tasks, it is difficult to prevent "floor" and "ceiling" effects in comparative studies. For example in the first experiment reported by Prior and Troup (1988), the error rate for both groups was only 15% in three of the four blocks of trials, implying a ceiling effect. However, in the second experiment when error rates increased to 37% for musicians and 50% for nonmusicians, a right-ear advantage for musicians emerged. Shanon (1981) has also attributed a lack of significant differences to floor and ceiling effects. In a series of three experiments with tasks of increasing difficulty, Shanon found no significant differences in the easiest task where error rates were 1.98% for the right ear and 1.74% for the left ear, or the most difficult task in which error rates were 51.21% for the right ear and 48.41% for the left ear. While the lack of significant results in the easiest task may have resulted from a ceiling effect, the absence of significant differences in the most difficult task may have resulted from a floor effect. Given that the tasks were a forced-choice design with two alternatives, subjects' performance on the most difficult task was at chance levels.

The diverse criteria used to differentiate levels of musical training may also be contributing to the contrariety of reported findings. While some researchers have found ear advantages using the modest criterion of four years of lessons and current performance in distinguishing between trained and untrained groups (Bever & Chiarello, 1974; Johnson, 1977), others have found the emergence of ear advantages only in trained musicians who were able to transcribe music (Johnson, et al., 1977). The importance of clearly discerning levels of musical training is also shown in a study by Gordon (1980). Gordon differentiated five levels of musical education and competence and found that subjects achieving higher levels of training demonstrated larger ear advantages. The findings of Gordon (1980) and Johnson et al. (1977) suggest that in studies which have failed to show group differences, subjects may not have achieved a sufficient level of competence to demonstrate a shift in ear advantage. Those studies which have not utilised comparison groups suffer the disadvantage of not being able to attribute lateral differences to training (e.g., Shanon, 1980).

Gaede, Parsons and Bertera (1977) have attempted to distinguish between the effects of aptitude and experience using the Drake Musical Aptitude Test. No ear advantages were found to be related to experience or high levels of aptitude. However, subjects measuring low in aptitude showed a left-ear advantage for determining the number of notes comprising a chord and a right-ear advantage for melody recognition. The absence of differences attributable to experience may have resulted from a modest criterion of five years of lessons to discern between high and low levels of experience. It should also be noted that the investigators used a monaural task. Additionally, it has been reported that tests of musical aptitude may not be indicative or predictive of those skills which contribute to a high degree of musical talent (Henson & Wyke, 1982). Notwithstanding, the findings of Gaede et al. would suggest that the effects of experience versus aptitude warrant further study.

Investigators have employed a tremendous diversity of stimuli and task requirements. Difficulty interpreting the empirical evidence arises from delineating those aspects of the task and stimulus to which the individual attends, particularly given the complex nature of certain types of musical stimuli. Many studies have used melodic excerpts as stimuli. Those studies in which melodic stimuli differed in both pitch and rhythm (e.g., Bever & Chiarello; Johnson, 1977; Johnson et al., 1977; Wagner & Hannon, 1981) found differences between groups. In contrast, experiments which held the rhythmic component of the melody constant did not yield group differences (Gordon, 1978; Zatorre, 1979).

Some investigators have attributed a left-ear advantage in nonmusicians for processing melodies, to their having employed a "holistic" strategy due to an inability to break down musical stimuli into various components (Bradshaw & Nettleton, 1981; Johnson et al., 1977; Peretz, 1987; Peretz, & Morais, 1980). Sergent (1983) points out the difficulty in operationalizing the analytic/holistic distinction and states that it is usually provided as a post hoc explanation, rather than an experimental test of distinct cognitive strategies. A study which attempted to induce a holistic processing strategy by directing subjects' attention to overall melodic contour of the melody failed to produce a left-ear advantage in nonmusicians (Peretz, Morais, & Bertelson, 1987). However, in the same study Peretz et al. did find that ear advantages for nonmusicians shifted from left to right when subjects were instructed to attend to critical notes in the melodies.

Some researchers have deployed stimuli of less complexity such as individual notes played on different instruments. This strategy was used in the first of Prior and Troup's (1988) experiments. However, while the experimenters assumed that subjects' judgements were based exclusively on discriminating among the different timbres of the instruments, failure to control for variations in amplitude may have contaminated the findings. Also, Prior and Troup measured reaction time as the dependent variable. While reaction time studies may eliminate possible contamination from a left-hemisphere advantage in many verbally mediated tasks, Bryden (1982) has argued that reaction time may in fact be more an indication of lateral differences in manual dexterity than hemispheric asymmetries in information processing. Sidtis (1980) has reported the emergence of a left-ear advantage in nonmusicians as the harmonic complexity of stimuli was gradually increased from pure tones to squarewaves. In a subsequent study, a left-ear advantage for nonmusicians was demonstrated for the perception of pure tones (Sidtis, 1981).

A number of studies using less complex acoustic stimuli have failed to control for musical experience. While it is reasonable to suggest that a greater number of the participant subjects would not have received musical training, these findings should be interpreted with caution. Left-ear advantages have been reported for piano tones (Sidtis & Bryden, 1978), different musical instruments (Kallman & Corballis, 1975), and four-note pure-tone patterns (Spreen, Spellacy, & Reid, 1970). In contrast, no ear advantages were reported for four-note frequency patterns, duration of tone pulses, or single notes played on a pipe organ in an experiment by Spellacy (1970). However, Spellacy did find a left-ear advantage for unfamiliar solo violin melodies. In a series of reaction-time experiments by Gates and Bradshaw (1977b), five-note sequences were constructed such that in any one sequence only one of three auditory parameters was altered, while others were held constant. Rhythm changes were accomplished by shortening or lengthening one of the five notes by half a beat. A pitch change resulted from raising or lowering one note a semitone. Similar five-element sequences in which each element was comprised of a major third interval were composed. Harmonic changes were achieved by raising or lowering one note in the interval. Gates and Bradshaw found a significant right-ear advantage for detecting a change in rhythm, however no ear advantages were found in either the pitch or harmony conditions. While there are problems with Gates and Bradshaw's methodology, their experiments represent one of the first attempts to isolate and control for different auditory parameters within individual stimuli.

It would seem that in order to clearly elucidate the possible differences in lateral asymmetries between musicians and nonmusicians using a dichotic procedure, a task is required which would detect a significant difference in the direction of ear advantage between groups. In order to allow for differences to emerge several factors would need to be controlled. First, the task would have to be sufficiently difficult for musically sophisticated subjects to diminish the chance of ceiling effects, yet easy enough for unsophisticated subjects to reduce floor effects. Second, it would seem necessary to establish a stringent criterion for delineating levels of musical competence or expertise. Third, the stimuli would need to be constructed such that the specific aspect of the stimulus that the subject was attending to, could be explicitly determined. Fourth, a dichotic monitoring procedure as suggested by Bryden (1982) would assist in limiting extraneous attentional variables. Fifth, the spectral and temporal nature of the competing stimulus should be similar enough to allow for ipsilateral suppression without fusion effects. Fusion or harmonic effects occur when temporal and spectral aspects of competing stimuli combine to create a meaningful total sound (Lauter, 1984). This factor is more relevant with nonverbal material and discerning two sounds may disadvantage musically sophisticated subjects who are accustomed to attending to harmony in stereo sounds. While ear asymmetries have been found using white noise as the competing stimulus (e.g., Springer, 1973), Zaidel (1977, cited in Henninger, 1981) has argued that subjects rapidly habituate to white noise and that reported effects are inconsistent. Henninger (1981) has successfully observed ear advantages employing noise produced from random tones generated at high speed, of the same spectral and frequency characteristics as the target stimuli. Additionally, handedness, family handedness background, and gender should be considered in the experimental design.

Walker's Cross-Modal Matching Task

Walker (1981) has purported that individuals tend to attribute explicit visual characteristics to movement or change in acoustical parameters. Specifically, changes in frequency are associated with vertical displacement; changes in amplitude are related to proportion or size; changes in waveform are identified with texture or pattern; and changes in duration are represented along a horizontal dimension. Walker draws convergent support for this notion from studies of the congenitally blind who tend to match tactile shapes to changes in auditory stimuli along the same physical dimensions (Walker, 1985; Welch, personal communication, August, 1989).

In a recent study, Walker (1987) tested subjects' ability to match auditory stimuli which varied in only one of four acoustic parameters to pictorial representations constructed according to those characteristics previously specified. Walker tested 838 subjects classified into five different cultural backgrounds and a sixth class of musically trained individuals; and stratified them across three different age levels, elementary school students, high school students, and adults. Three major findings emerged from Walker's study. First, while untrained subjects performed above chance levels, musical training was found to be a significant factor in differentiating subjects' ability to achieve higher scores. Although cultural and environmental variables, specifically proximity and exposure to Western life style were found to distinguish one group, and differences between the first and third levels of age for the musically trained group was found to be significant, performance of the musically trained groups was significantly better in comparisons with each of the other groups. Second, there were no significant differences attributable to the acoustic parameter manipulated in the stimulus. Third, those with musical training were more adept discerning changes in all four acoustic parameters.

These latter two findings are pertinent to the notion that acoustical parameters can be distinguished according to amodal and modal-specific qualities (Walker, 1987). Lewkowicz and Turkewitz (1980) distinguish an amodal feature as being perceptible in more than one sensory modality. For example intensity, duration, and texture, are amodal qualities. Modal-specific refers to features which are only identifiable in one modality, such as "sweetness" or pitch. It is proposed that many amodal qualities are innately "hardwired," implying cross-modal or multisensory equivalence, in contrast to modal-specific properties which require some degree of learning or the intervention of higher cognitive processes to achieve cross-modal integration (Marks, 1978). Thus, in Walker′s study it might have been expected that musically sophisticated subjects would perform significantly better on pitch discrimination tasks due to cross-modal integration engendered by training. In tasks requiring judgments pertaining to amodal properties such as amplitude, waveform, or duration, training would not be expected to contribute as strongly to subjects′ performance.

Goldberg and Costa (1981) have posited that due to increased interregional connectivity, the right hemisphere is more proficient at simultaneous processing of information accruing from dissimilar modalities. However as an event becomes routinized, the formation of a cognitive code may act to merge multimodal information into a unitary modality (Conrad, 1973). Musical training may precipitate a left-hemisphere advantage for matching visual metaphors to discrete changes in acoustic parameters due to a developed cognitive code which allows the translation of divergent multimodal information into a single modality. Untrained subjects may show a left-hemisphere advantage for those amodal parameters which are represented as innate cognitive codes. However in making discriminations of modal-specific properties such as pitch, untrained subjects might be expected to demonstrate a right-hemisphere advantage without the benefit of established codes.

Walker's (1987) cross-modal matching paradigm provides a "do-able" task for musicians and nonmusicians which demonstrates significant differences in performance while effectively controlling for the manipulation of discrete acoustic parameters. Also, verbal mediation would not seem to be a necessary aspect of task performance (Walker, 1981), eliminating spurious effects from a left-hemisphere advantage for some language functions. It seems reasonable to suggest that employing a dichotic presentation of Walker's paradigm might serve to further elucidate differences in hemispheric asymmetry between musically trained and untrained subjects, and discern possible asymmetries for amodal and modal-specific acoustic parameters .

Summary

Goldberg and Costa's (1981) model of left-hemisphere advantage for familiar tasks and right-hemisphere advantage for novel tasks seems useful to explain observed lateral asymmetries. An implication of their theory is that differential hemispheric activation is subject determined, but that education can act to influence the deployment of differential hemispheric functions. Musical training would seem a suitable domain for a test of Goldberg and Costa's model due to the fact that musical training is not mandatory in public education as is reading and writing. It is possible to acquire a sample of untrained adults who can comprehend the instructions of a dichotic task but are less experienced with respect to the specified materials. This would not be as possible with other areas.

While the evidence from studies investigating lateral differences between musically trained and untrained subjects has been inconsistent, it is suggested that failure to adequately control for factors such as: level of musical training, task difficulty, nature of the competing stimulus, strategy and attentional variables, handedness, family handedness background, and gender, has contributed to much of the variability in reported findings.

It is proposed that a dichotic version of Walker's (1987) task might afford an opportunity to investigate the effects of musical training on lateral asymmetries under task conditions which are of moderate difficulty for both trained and untrained subjects, and in which acoustic parameters are adequately controlled.

Additionally, differentiating lateral asymmetries for distinct acoustic parameters may prove to be of value in the same manner that delineating the simpler components of verbal language helped to expand the framework in which to view lateral asymmetries, and cast doubt as to the efficacy of the verbal/nonverbal dichotomy (cf., Bradshaw & Nettleton, 1981).

Hypotheses of the Present Study

On the basis of the preceding literature review, the following null hypotheses are proposed to be tested:

1. There will be no difference in accuracy between musicians and nonmusicians with respect to matching appropriate visual metaphors to auditory stimuli.

2. There will be no difference in accuracy of performance between the two orders of presentation.

3. There will be no difference in accuracy of performance between stimuli presented to the left and right ears.

4. There will be no differences in accuracy between the four acoustical parameters manipulated in the auditory stimuli.

5. There will be no difference in the patterns of asymmetry as relected by the laterality index lambda, between stimuli which manifest amodal and modal-specific properties.

6. There will be no difference in the direction of lambda scores between musicians and nonmusicians.

7. There will be no difference in the magnitude of lambda scores between musicians and nonmusicians.

8. There will be no difference in accuracy between the first and second trials on each ear.

CHAPTER II

METHOD

Subjects

The subjects were 40 male university students who volunteered to participate in the study without financial remuneration. There were 20 musicians and 20 nonmusicians. Musicians were predominantly third and fourth year music majors who met all five criteria: (a) having a minimum of seven years lessons on an instrument, (b) attainment of grade nine on the Royal Conservatory exams, (c) a minimum of two years of university as a music major, (d) self-reported ability to transcribe music, and (e) actively playing an instrument more than 10 hours per week. Individuals who had not taken the Royal Conservatory exams required a minimum of 10 years of lessons. The nonmusicians were predominantly undergraduates who met all four criteria: (a) having no formal training in music theory, (b) no more than one year of lessons on an instrument, (c) no lessons in the last five years, and (d) not actively playing an instrument. The subjects ranged in age from 18 to 36 with a mean age of 24.3 for musicians and 24.9 for nonmusicians.

All subjects were right handed as determined by Bryden's (1982) five-item preference inventory, with no left-handed relations in their biological families of origin. None of the subjects had any known hearing deficit or perfect pitch.

Stimuli

The 16 auditory stimuli constructed by Walker (1987) consist of four items for each acoustic parameter: frequency, waveform, duration, and amplitude. Each stimulus was digitally recorded using an Emu Systems digital sampler (Model Emulator II). The sampled stimuli were edited such that all stimuli were three seconds in duration, independent of the discrete changes in each stimulus. Although the edited stimuli deviated from Walker's original stimuli with respect to overall pitch, the integrity of the change in acoustic parameter was preserved. The 16 audio stimuli were randomized into four consecutive blocks of 16 trials such that each of the 16 stimuli was present in each of the four blocks. The sequence of presentation was programmed using Steinberg Pro 24 compositional software on an Atari computer (Model 1040ST). Each three-second stimulus was followed by an eight second interstimulus interval. The competing stimuli consisted of three-second segments of random pure tones. The pure tones were generated at a rate of 22 tones per second in order to simulate noise. The four blocks of stimuli and pure-tone segments were recorded on to five tracks of an Akai multitrack tape recorder (Model 1212) at a speed of 19 ips. Each of the four blocks of trials was recorded consecutively on a Casio stereo digital tape recorder (Model DA 2) in an ABBA format with the competing stimuli on the opposing channel. To ensure the level of task difficulty would not produce floor effects for nonmusicians or ceiling effects for musicians, extensive pilot testing was carried out to determine an appropriate adjustment of the overall tape speed.

The digital tape format was used to control for the effects of "print through," which occurs when doing analog tape recordings. Print through is the transfer of portions of the magnetic field imprinted on tape to adjacent locations on the tape. This results in recorded auditory signals from one part of the tape becoming audible on other areas of the tape. This effect is accentuated during unrecorded or blank segments which precede or follow the recorded segments, with the absence of recorded auditory signal to "mask" the print through. Print through is most apparent when using slower recording speeds and narrow tape such as standard audio cassettes.

Walker's (1987) original 16 sets of visual metaphors were used (see Appendix A), each set corresponding to an auditory stimulus. For each of the four presentations of each auditory stimulus, the four pictorial response alternatives in the set were randomly assigned to a different order on the test to avoid subjects choosing visual stimuli on the basis of position.

Apparatus

Tapes were played on a Casio digital tape recorder (Model DA2). Subjects listened over AKG headphones (Model K340) which had been calibrated for equal channel intensity. Stimuli were presented at 70db.

Procedures

After filling out the musical experience and handedness/ family handedness background questionnaire (adapted from Henninger, 1981, see Appendix B), subjects were presented with the stimulus tape. Each subject was presented with four blocks of 16 trials for a total of 64 trials. Testing was preceded by recorded instructions. Prior to each block of trials, subjects were instructed to attend to a specific ear and choose the visual representation which best matched the sound heard in that particular ear. Subjects were asked to indicate their choices by circling one of four visual metapors which corresponded to each sound. Half the subjects heard the stimuli in a right, left, left, right order; the other half, in a left, right, right, left order. An experimental session lasted 25 minutes.

CHAPTER III

RESULTS

Overview of the Analysis Procedure

The results are organized into five main sections: (a) descriptive statistics; (b) multivariate analysis of the error scores; (c) corresponding univariate analysis of the error scores and post hoc comparisons; (d) analysis of difference scores employing the laterality index, lambda; and (e) univariate and post hoc analyses of the error scores in relation to trials.

Descriptive Statistics

The total errors made by nonmusicians ranged from 7 to 31 out of a possible 64 with a mean error score of 15.95 (s.d.=5.36). The mean error score for nonmusicians on the left ear was 7.3 (s.d.=3.06) and for the right ear was 8.65 (s.d.=2.56). The total errors made by musicians ranged from 4 to 25 with a mean of 10.1 (s.d.=4.76). The mean error score for musicians on the left ear was 5.45 (s.d.=2.8) and for the right ear was 4.65 (s.d.=2.18). These scores are shown in Figure 1.

The means and standard deviations for the error scores on the frequency, waveform, duration, and amplitude items are shown in Table 1. No errors were committed by musicians on

Figure 1

Mean Error Scores

By Ear and By Musical Training

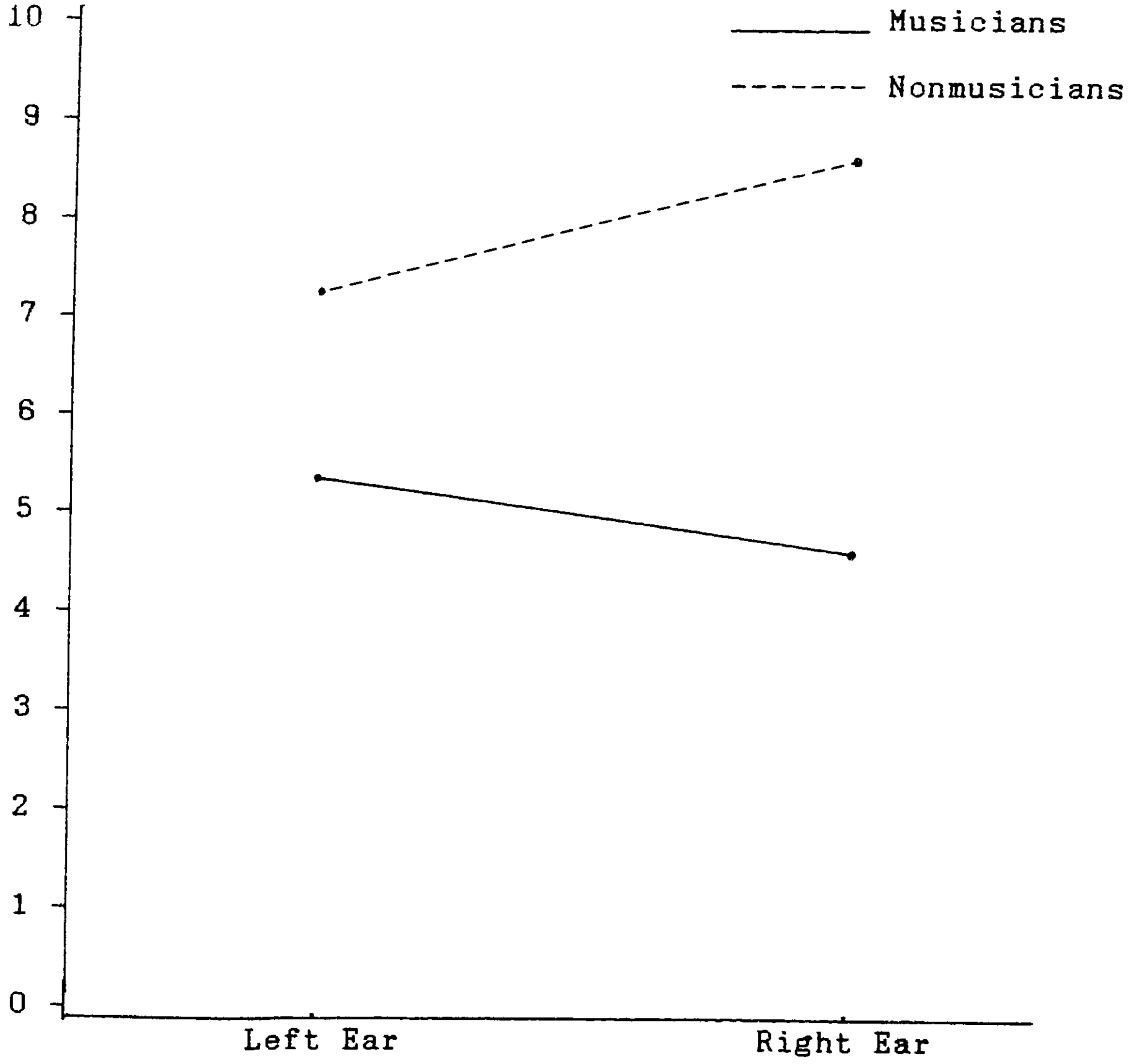


Table 1

Means and Standard Deviations

For Frequency, Waveform, Duration, and Amplitude Items

	Musicians	Nonmusicians
Frequency		
Left	0.70 (s.d.=1.08)	1.45 (s.d.=1.43)
Right	0.55 (s.d.=0.95)	1.85 (s.d.=1.46)
Waveform		
Left	2.60 (s.d.=1.39)	3.00 (s.d.=1.45)
Right	2.05 (s.d.=1.05)	3.25 (s.d.=1.41)
Duration		
Left	0.00 (s.d.=0.00)	0.80 (s.d.=1.20)
Right	0.00 (s.d.=0.00)	1.05 (s.d.=1.19)
Amplitude		
Left	2.15 (s.d.=1.84)	2.05 (s.d.=1.47)
Right	2.05 (s.d.=1.28)	2.50 (s.d.=1.43)

the duration items indicating that a ceiling effect had occurred. As seen in Table 1, for all other comparisons between ears, musicians committed fewer errors on right ear items while nonmusicians committed fewer errors on left ear items.

Multivariate Analysis

Using SPSS MANOVA, a 2 X 2 X 2 multivariate analysis of variance was performed on four dependent variables: the error scores on (a) frequency, (b) duration, (c) waveform, and (d) amplitude items. There were two between-groups factors, order (left, right, right, left; right, left, left, right) and musical training (musicians, nonmusicians). Ear (left, right) was a within-groups factor.

With the use of Hotelling's trace criterion, the combined dependent variables were significantly affected by musical training (F(4,33)=5.35, p=.002). Thus, the first null hypothesis, that there would be no differences in performance between musicians and nonmusicians was rejected. The main effect for order was not significant (F(4,33)=.50, p=.733). The musical training by order interaction was not significant (F(4,33)=.09, p=.984). The main effect for ear was not significant (F(4,33)=.90, p=.477), nor was the order by ear interaction (F(4,33)=.43, p=.789). Thus, the second null hypothesis, that there would be no differences between the

two orders of presentation, is tenable. The musical training by ear interaction was significant (F(4,33)=4.43, p=.006). Thus, the third null hypothesis, that there would be no difference between the left and right ears was rejected. The order, by musical training, by ear, three-way interaction was not significant (F(4,33)=.05, p=.995).
These results are shown in Table 2.

Univariate Analysis and Post Hoc Comparisons

To investigate the significant multivariate main effect of musical training and the significant multivariate musical training by ear interaction, corresponding univariate F-tests were performed on the composite error scores and for each of the dependent variables (Tabachnick & Fidell, 1983).

A 2 X 2 X 2 analysis of variance was performed on the composite error scores with two between-groups factors, order and musical training, and one within-groups factor, ears. As shown in Table 3, there was a significant effect of musical training (F(1,36)=12.66, p=.001) and a significant musical training by ear interaction (F(1,36)=15.22, p=.001). There were no other significant main effects or interactions. Using the Newman-Keuls method of multiple comparisons (Winer, 1971), all mean differences were significant. Significant differences of specific interest are those between: left and right ears for musicians (NK(36,2)=2.91, p<.05), left and

Table 2

Multivariate Analysis of Variance of Error Scores Using Hotelling's Trace Criterion

Source	Eigenvalue	Exact F	Hypothesis DF	Error DF	Sig. of F
Musical Training(MT)	.64849	5.35005	4	33	.002
Order	.06109	.50400	4	33	.733
Ear	.10878	.89742	4	33	.477
Order X MT	.98892	.09241	4	33	.984
MT X Ear	.53699	4.43017	4	33	.006
Order X Ear	.05155	.42529	4	33	.789
Order X MT X Ear	.00609	.05026	4	33	.995

Table 3

Analysis of Variance Summary Table For Composite Error Scores

Source	SS	DF	MS	F	p
Musical Training	171.113	1	171.113	12.663	.001
Order	.613	1	.613	.045	.883
Musical Training X Order	.313	1	.313	.023	.880
Error (Within)	486.450	36	13.513		
Ear	1.514	1	1.514	.997	.325
Musical Training X Ear	23.110	1	23.110	15.224	.001
Order X Ear	.112	1	.112	.074	.787
Musical Training X Order X Ear	.115	1	.115	.076	.785
Error (Within)	54.650	36	1.518		

right ears for nonmusicians (NK(36,2)=4.91, p<.05)), left ear scores for musicians and nonmusicians (NK(36,2)=6.73, p<.05), and right ear scores for musicians and nonmusicians (NK(36,4)=14.55, p<.05). The proportion of variance that can be accounted for by musical training, ω^2 (Hays, 1963), reflects a strong association for musical training to the right ear (ω^2=.4042),in contrast to a weaker association to the left ear (ω^2=.0679).

The results of the separate univariate F tests performed on each of the dependent variables, frequency, duration, waveform, and amplitude, are shown in Tables 4,5,6, and 7, respectively. The main effect for musical training was significant for frequency (F(1,36)=7.24, p=.011), duration (F(1,36)=13.09, p=.001), and waveform (F(1,36)=4.31, p=.045). The musical training by ear interaction was shown to be significant for frequency (F(1,36)=5.26, p=.028) and waveform (F(1,36)=4.70, p=.037). Thus, the fourth null hypothesis, that there would be no differences between the four acoustic parameters was rejected.

In order to further explicate the musical training by ear interaction effects, separate Newman-Keuls procedures were performed on the frequency and waveform mean error scores. Comparisons of the means for frequency showed that while all other comparisons were significant, the difference between left and right-ear errors for musicians was not

Table 4

Analysis of Variance Summary Table

For Error Scores on Frequency Items

<u>Source</u>	<u>SS</u>	<u>DF</u>	<u>MS</u>	<u>F</u>	<u>p</u>
Musical Training	21.01250	1	21.01250	7.23529	.011
Order	2.81250	1	2.81250	.96844	.332
Musical Training X Order	.61250	1	.61250	.21090	.649
Error (Within)	104.55000	36	2.90417		
Ear	.31250	1	.31250	1.08696	.304
Order X Ear	.31250	1	.31250	1.08696	.304
Musical Training X Ear	1.51250	1	1.51250	5.26087	.028
Musical Training X Order X Ear	.01250	1	.01250	.04348	.836
Error (Within)	10.35000	36	.28750		

Table 5

Analysis of Variance Summary Table For Error Scores on Duration Items

Source	*SS*	*DF*	*MS*	*F*	*p*
Musical Training	17.11250	1	17.11250	13.09352	.001
Order	.11250	1	.11250	.08608	.771
Musical Training X Order	.11250	1	.11250	.08608	.771
Error (Within)	47.05000	36	1.30694		
Ear	.31250	1	.31250	1.64234	.208
Order X Ear	.01250	1	.01250	.06569	.799
Musical Training X Ear	.31250	1	.31250	1.64234	.208
Musical Training X Order X Ear	.01250	1	.01250	.06569	.799
Error (Within)	6.85000	36	.19028		

Table 6

Analysis of Variance Summary Table

For Error Scores on Waveform Items

Source	SS	DF	MS	F	p
Musical Training	12.80000	1	12.80000	4.31057	.045
Order	3.20000	1	3.20000	1.07764	.306
Musical Training X Order	.05000	1	.05000	.01684	.897
Error (Within)	106.90000	36	2.96944		
Ear	.45000	1	.45000	.66122	.421
Order X Ear	.80000	1	.80000	1.17551	.285
Musical Training X Ear	3.20000	1	.20000	4.70204	.037
Musical Training X Order X Ear	.05000	1	.05000	.07347	.788
Error (Within)	24.50000	36	.68056		

Table 7

Analysis of Variance Summary Table

For Error Scores on Amplitude Items

Source	SS	DF	MS	F	p
Musical Training	.61250	1	.61250	.14824	.702
Order	.31250	1	.31250	.07563	.785
Musical Training X Order	.01250	1	.01250	.00303	.956
Error (Within)	148.75000	36	4.13194		
Ear	.61250	1	.61250	.83681	.366
Order X Ear	.01250	1	.01250	.01708	.897
Musical Training X Ear	1.51250	1	1.51250	2.06641	.159
Musical Training X Order X Ear	.01250	1	.01250	.01708	.897
Error (Within)	26.35000	36	.73194		

significant (NK(36,2)=1.25, $p>.05$). The results demonstrate that for frequency, musical training accounted for more of the variance on the right ear ($\omega^2=.2026$) than the left ear ($\omega^2=.0577$). With respect to waveform, comparisons of the means showed that while left-right ear differences for musicians was significant (NK(36,2)=2.98, $p<.05$), ear differences for nonmusicians was not significant. All other comparisons between means were significant except for the difference between musicians and nonmusicians on the left ear. As was the case with frequency, musical training accounted for more of the variance on right ear ($\omega^2=.1725$) than left ear waveform items ($\omega^2=.0065$).

Laterality Index

The lambda coefficient (Bryden & Sprott, 1981)), a laterality index, was computed for each subject using the composite error scores. Lambda is calculated as the natural logarithm of: $X_R(n-X_L)/X_L(n-X_R)$; where X_R is right ear errors, X_L is left ear errors, and n is the number of trials. According to Bryden and Sprott, lambda is mathematically uncorrelated with overall accuracy. A positive value of lambda indicates a greater number of errors on the right ear or a left-ear advantage, a negative lambda value indicates a right-ear advantage, and a lambda of zero indicates no ear advantage. The number of subjects showing right, left, and no ear advantage as measured by the laterality index is shown in Table 8. The lambda scores were subjected to a 2 X 2 analysis of variance with order and musical training as between-groups factors. As shown in Table 9, there was a significant effect of musical training (F(1,36)=11.88, p=.001). Significantly more musicians show a right-ear advantage in contrast to nonmusicians who show a left-ear advantage. Thus, the sixth null hypothesis, that there would be no difference in direction of lambda scores between musicians and nonmusicians, is rejected.

The absolute lambda scores were subjected to a 2 X 2 analysis of variance with order and musical training as between-groups factors. As shown in Table 10, no significant differences between groups were found for the magnitude of lambda. Thus, the seventh hypothesis, that there would be no difference in the magnitude of lambda scores between musicians and nonmusicians is tenable.

Separate lambda values for each subject were also computed on the error scores for each of the four acoustic parameters. The lambda values were subjected to a 2 X 2 X 4 analysis of variance with order and musical training as between-groups factors, and the four types of acoustic parameters, a within subjects factor. As shown in Table 11, there was a significant main effect for musical training (F(1,36)=7.25, p=.011). There were no other significant main

Table 8

Number of Subjects Displaying Right, Left, and No Ear Advantage as Indicated by Lambda

Group	Right Ear Advantage	Left Ear Advantage	No Ear Advantage
Musicians	11	4	5
Nonmusicians	4	14	2

Table 9

Analysis of Variance Summary Table
For Direction of Lambda Scores

Source	SS	DF	MS	F	p
Musical Training	1.981	1	1.981	11.878	.001
Order	.004	1	.004	.022	.884
Musical Training X Order	.075	1	.075	.447	.508
Error (Within)	6.006	36	.167		

Table 10

Analysis of Variance Summary Table

For Magnitude of Lambda Scores

Source	*SS*	*DF*	*MS*	*F*	*p*
Musical Training	.000	1	.000	.000	.988
Order	.031	1	.031	.302	.586
Musical Training X Order	.067	1	.067	.659	.422
Error (Within)	3.646	36	.101		

Table 11

Analysis of Variance Summary Table For Lambda Scores For Frequency, Duration, Waveform, and Amplitude

Source	SS	DF	MS	F	p
Musical Training	9.582	1	9.582	7.251	.011
Order	.970	1	.970	.734	.397
Musical Training X Order	2.066	1	2.066	1.564	.219
Error (Within)	47.575	36	1.322		
Acoustic Parameter (AP)	4.813	3	1.604	.828	.481
Musical Training X AP	2.370	3	.790	.408	.748
Order X AP	2.755	3	.918	.474	.701
Musical Training X Order X AP	1.570	3	.523	.270	.847
Error (Within)	209.186	108	1.937		

effects or interactions, indicating that lambda values for frequency items were not significantly different from lambda values for the other acoustic parameters. Thus, the fifth null hypothesis, that there would be no differences in the patterns of asymmetry between amodal and modal-specific parameters remains tenable.

Trials

To investigate whether practice affected differences in performance, a 2 X 2 X 2 X 2 analysis of variance was computed on the errors committed during first and second trials for each ear (see Table 12). The between-groups factors were order and musical training, with trials (first, second) and ear (left, right) as within-groups factors. A significant main effect with Bonferroni correction was shown for musical training ($F(1,36)=12.06$, $p<.05$). No other main effects or interactions were significant. Thus, the eighth null hypothesis, that there would be no differences between first and second trials, is tenable.

Table 12

Analysis of Variance Summary Table For Error Scores on Trials

Source	SS	DF	MS	F	p
Order	.079	1	.079	.012	.915
Musical Training (MT)	81.087	1	81.087	12.056	.001
MT X Order	1.487	1	1.487	.221	.641
Error (Within)	242.136	36	6.726		
Ear	.293	1	.293	.306	.583
Order X Ear	2.348	1	2.348	2.455	.126
MT X Ear	.007	1	.007	.007	.932
MT X Order X Ear	2.552	1	2.552	2.668	.111
Error (Within)	34.435	36	.957		
Trials	1.075	1	1.075	.965	.333
Order X Trials	.524	1	.524	.470	.497
MT X Trials	.524	1	.524	.470	.497
MT X Order X Trials	1.075	1	1.075	.965	.333
Error (Within)	40.119	36	1.114		
Ears X Trials	1.519	1	1.519	1.290	.263
Order X Ears X Trials	2.039	1	2.039	1.733	.196
MT X Ears X Trials	.417	1	.417	.354	.555
Order X MT X Ears X Trials	.202	1	.202	.172	.681
Error (Within)	42.369	36	1.177		

CHAPTER IV

DISCUSSION

In this section, there will be a discussion of the major findings of this study in relation to a model of hemispheric function. Methodological issues arising from this study will be addressed. Additionally, recommendations for further empirical work will be made.

Discussion of Major Findings

A major finding in this study is that musicians and nonmusicians show opposite patterns of asymmetry in performing the matching task. The finding that musical training accounted for 40% of the variance on right-ear scores in contrast to 7% on left-ear scores, emphasizes the role of the left hemisphere in contributing to the increased accuracy of musicians′ performance. In light of Goldberg and Costa′s (1981) model, this augmented right-ear advantage exhibited by musicians could be interpreted as a reflection of pre-existent descriptive codes accessed in the left hemisphere. Goldberg (1989) proposes a "gradiental" relationship between the cerebral hemispheres, of relative participation in the broad spectrum of cognitive processes. As we learn to codify events along certain dimensions, the rules governing codification become specific algorithms or schemata. These cognitive structures are subsequently employed in internal processes of organization. It is possible that the more an algorithm is developed, not only is it performed more rapidly, but less information may be required to reach the threshold for which the algorithm is executed. If as Goldberg and Costa (1981) suggest, such algorithms are gradually relegated to more compact and accessible structures in the left hemisphere with increased familiarity and the successful resolution of tasks, then inversely, there will be less need for right-hemisphere involvement in the task. Specifically, the less an event is deemed novel, the less interconnected right-hemisphere structures are required to assemble a strategy in dealing with the task. Cognitive functions may be represented along a continuum of relative involvement between the cerebral hemispheres.

Relevant dimensions or parameters required for the codification of an acoustic event would be frequency, waveform, duration, and amplitude. The algorithm for discerning changes in a sound might be structured around the general rule of looking for coherence among temporally adjacent units of information. A learning algorithm based on such a rule has been suggested by Hinton (in press). For musicians, it may be that certain properties of sound invoke algorithms or schema. Being relatively more familiar with task demands, musicians may also be advantaged by a more immediate cognitive procedure and less information being conditional for its execution.

This view of hemispheric function provides for notions of both complementarity and convergence. The model proposed is founded on an adaptive feature, the propensity for drawing similarities, recognizing patterns, and making comparisons on the basis of prior experience. Under normal conditions, the hemispheres act in concert. Each hemisphere receiving highly similar sensory input, imposes a different pattern of cognitive structures. The right hemisphere acts on perceived novel aspects, the left hemisphere provides algorithmic procedures based on perceived similarities with prior experience. While some have argued that hemispheric complementarity is statistical as opposed to functional (Bryden, Hécaen, & DeAgostini, 1982), these claims have been based on a verbal-spatial dichotomy. The characterization of the left hemisphere as "the language hemisphere" (Bryden, 1982) may be less appropriate in strict reference to verbal language. Rather, the term language might be more analogous to a computer programming language, a generic code for constructed algorithms unconstrained by specific stimulus classes. Thus, anatomical division and observed asymmetries in performance may not reflect hemispheric specialization for specific stimulus classes or generalized cognitive modes.

Rather, the distinction between hemispheric processes may be based on the manner in which information is processed and learning takes place.

It is also important to note that conceptualizing hemispheric functions in this way relies on a more complex model of cerebral operations. Such a model would have less in common with more traditional information-processing theories emphasizing sequentially ordered, hierarchical components (e.g., Moscovitch, 1986). Rather, it becomes necessary to conceive of cerebral processes as occurring in a parallel fashion with information being simultaneously dispersed and manipulated in various locations, as posited by connectionist models (cf. Hinton & Anderson, 1989).

The finding of no significant differences in lambda between amodal and modal-specific forms of stimuli, may be viewed as concordant with the model. Discriminating amodal features may be a more "hardwired" function present at birth, and learning to represent changes in frequency along a vertical dimension may require the intervention of higher cognitive structures (Marks, 1978). However, the notion that hardwired descriptive codes for processing amodal parameters might be demonstrated as a left-hemisphere advantage for both musicians and nonmusicians is not supported by this study. Although it is possible that a change in lateralization may occur during maturation, it would seem that for adult males, the amodal or modal-specific character of the stimulus is not a determinant of hemispheric asymmetries.

Significant musical training by ear interactions were only found for frequency and waveform items. However, the difficulty of items in the four acoustic parameters was not equal and thus, error scores for each parameter are not directly comparable. While a ceiling effect for duration items inhibits speculation, the scores for amplitude items were in the expected direction, and it is conceivable that significant differences would emerge with additional subjects. Thus, the nature of the acoustic parameter may also not be a determinant of hemispheric asymmetries.

The finding of no significant musical training by trial interactions for either ear, would seem to indicate an absence of practice effects. It might be argued that practice effects could emerge with additional blocks of testing. However, the finding that increased accuracy was associated with an opposite pattern of lateral asymmetries may indicate that without learning and possibly instruction, experience gained through practice may be insufficient to increase accuracy. Increased accuracy may be contingent upon individuals′ ability to automate some aspects of the task. Focal, compact structures in the left-hemisphere may be a more efficient use of memorial resources than diffuse right-hemisphere structures. If the task places maximum demands on memorial and processing resources in the right hemisphere of untrained subjects, it is conceivable that a ceiling exists for right-hemisphere capability. Beyond a certain point, a shift in the direction of hemispheric activation must occur before more efficient and accurate processing can take place. It is proposed that musicians' superior performance on the cross-modal matching task results from having automated some aspects of the task, thereby making more efficient use of limited cerebral resources.

Methodological Issues

This study represents a significant attempt to control for the effects of print through. Many studies which have failed to control for print through may have in fact, not been dichotic studies. Inadvertently exposing subjects to random monaural presentations of the target stimulus prior to the experimental trial, may bias subjects' responses. Although there are no reported studies comparing the effects of print through in a dichotic paradigm, the effects of brief exposure to stimuli has been reliably demonstrated in what Zajonc (1980) has termed the "exposure effect." The exposure effect occurs when subjects are initially shown stimuli at an exposure duration which does not permit recognition. In subsequent testing, subjects report a preference for those stimuli which they have received brief exposure to, over stimuli with which they have had no prior experience (Moreland & Zajonc, 1977, 1979; Kunst-Wilson & Zajonc, 1980). Thus, prior exposure to target stimuli at even seemingly imperceptible levels may in fact contribute to specious experimental effects.

The exposure effect may also be relevant to many dichotic studies which have used the same stimuli as both target and competing stimuli in experimental trials (e.g., Bryden, 1986; Bryden, Ley, & Sugarman, 1982; Prior & Troup, 1988). The common practise of pairing stimuli with every other stimulus except itself to construct the dichotic pairs, may bias subjects' responses to those stimuli with which they have received prior exposure. In the present study, the use of random tones generated at a high rate of presentation as competing stimuli, not only eliminates fusion effects, but also avoids the possibility of spurious effects engendered by preexposing subjects to target stimuli.

The results of this study would suggest that the cross-modal matching task served as an effective means in discerning lateral asymmetries in musicians and nonmusicians. As well as allowing for explicit control of the aspect of sound being attended to, the task does not necessarily require verbal mediation. While some might argue an advantage for individuals with an increased ability for visual imaging, such an advantage has been more readily attributed to the right hemisphere (Ley, 1983). If visual-imaging ability was integral to performing the task, musicians would be expected to show a right-hemisphere advantage. The assumption that the cross-modal matching task requires imaging ability or a process by which auditory information is transferred to the visual domain is somewhat problematic. It has been posited that intersensory analogies are derived from "an intrinsic unity of the senses" (Marks, 1978, p. 181). Auerbach and Sperling (1974) found that when subjects were required to make same-different judgments about the spatial origin of: two auditory stimuli, two lights, or an auditory stimulus and a light; no variance could be attributed to translating from one spatial representation to another. Auerbach and Sperling argue that visual and auditory sensations are represented in a common perceptual space. The term imagery need not imply the notion of transfer or mediation from one sensory modality to another. Rather, there may be a single cognitive space which is common to information accruing from all sense modalities.

Additionally, the stringent criteria employed for distinguishing between musically trained and untrained subjects also may have been a major factor in obtaining the observed asymmetries.

Recommendations For Further Research

The results of this study would suggest that music is a productive domain for investigating cerebral functions. The observed patterns of asymmetry and espoused model of hemispheric functions may offer at least, a partial explanation for Walker's (1987) findings of superior performance by musically trained subjects.

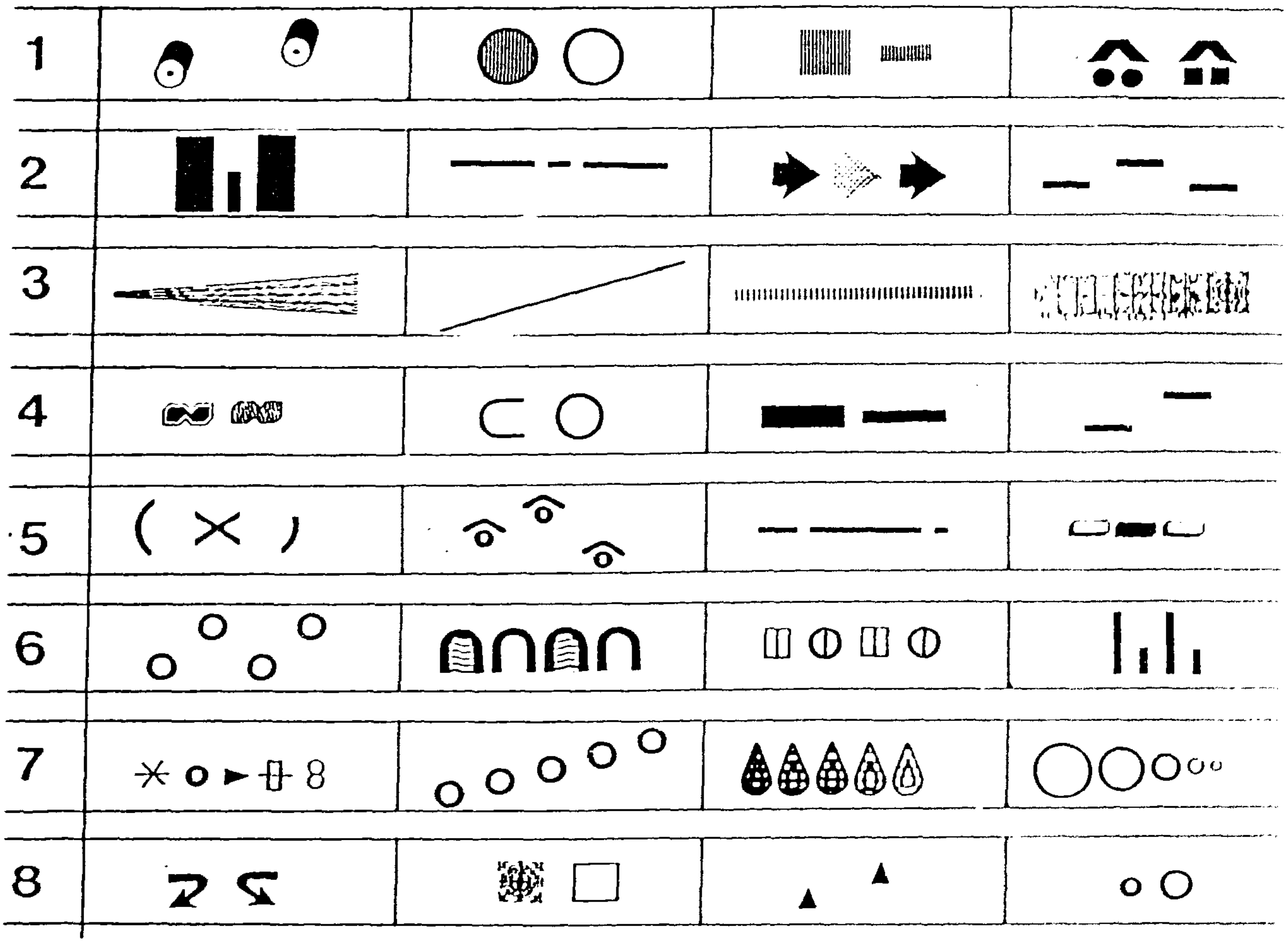
It was beyond the scope of this study to distinguish between the effects of formal musical training and experience. Comparing musicians with varying degrees of formal education (e.g., Gordon, 1980) may help to differentiate particular aspects of training which promote the development of requisite cognitive structures. It may also be of value to observe groups of individuals such as recording studio engineers, who may have no musical training, but are used to making discrete judgments about sound.

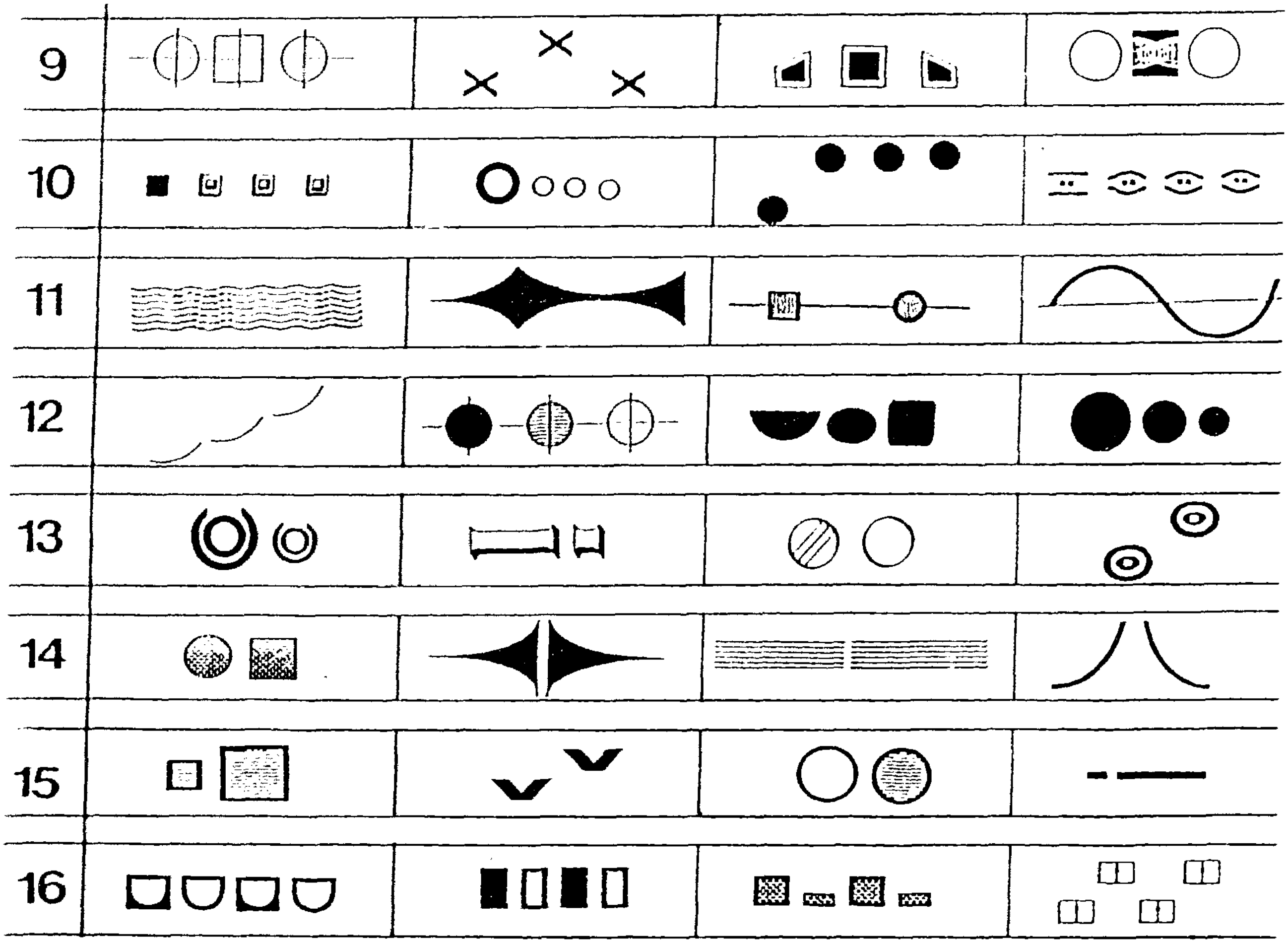
In the present study, distinguishing subjects on the basis of musical training was effective in demonstrating hemispheric asymmetries. The results suggest that in tests of lateral asymmetries, it is important to control for domain specific knowledge which may advantage particular individuals in the experimental task. The strategy of manipulating subject variables such as education, age, gender, and individual strategies may provide further evidence for understanding lateralized effects. However, while investigations of hemispheric asymmetries have been valuable in drawing attention to differences in hemispheric function, emphasizing these differences has overshadowed the convergent nature of lateral processes. Refocusing on the complementary aspects of hemispheric process, rather than complementary classifications based on specific stimulus content, may prove to be more profitable in elucidating cerebral functions.

Additionally, the significant findings in this study may be largely related to the audio quality of the dichotic task. Until more is understood about the extraneous effects of print through, care should be exercised in the construction and administration of auditory tasks.

APPENDIX A

Visual Metaphors

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APPENDIX B

Musical Training and Handedness Questionnaire

Gender: male( ) female ( )

Age: ______

Musical Training

1. Do you play an instrument? yes______ no______

If yes, which instrument(s)? ________________________________

2. Have you had vocal training? yes______ no______

3. Do you sing in a choir? yes______ no______

4. Do you read music? yes______ no______

5. Can you transcribe music? yes______ no______

6. If you heard a piece performed slowly, twice, could you write down the notes for a:

folk song with chords: yes______ no______
hymn with harmony: yes______ no______
familiar melody: yes______ no______
unfamiliar melody: yes______ no______
string quartet: yes______ no______
orchestral phrase: yes______ no

7. Do you have perfect pitch? yes______ no______

8. Do you have any known hearing difficulties? yes______ no______

9. Do you consider yourself a:

musician______ nonmusician______

10. Have you ever had music lessons? yes______ no______

If yes, for how many years?________ How long ago?________

11. How many years of formal music education at the university level have you had?________

12. What is the highest level you have attained at the Royal Conservatory on an instrument?_______

Which instrument(s)?______________________

Highest level of theory?__________

13. Are you currently practicing or performing?

yes______ no______

14. How many hours per week do you practise or perform?

less than one______ 1 to 5______

5 to 10 _____ more than 10_____

15. At what level are you performing?

student_____ semi-professional____ professional____

16. When you listen to music, is it more often:

as background for another task _____

usually the main activity_____

17. How many hours per week do you listen to music?

less than one______ 1 to 5_____

5 to 10______ more than 10_____

18. How important was music in your home when you were growing up?

unimportant___ moderately important____

important____ very important______

19. How important is music in your life now?

unimportant___ moderately important____

important____ very important______

Handedness

20. Do you consider yourself:

right-handed______ left-handed______ ambidextrous____

21. Which hand do you prefer to throw a ball with?

right____ left_____ both equally______

22. Which hand do you prefer to brush your teeth with?

right____ left_____ both equally______

23. Which hand do you prefer to write a message with?

right____ left_____ both equally______

24. Which hand do you prefer to draw a picture with?

right____ left_____ both equally______

25. Which hand do you prefer to hold scissors when cutting something?

right____ left_____ both equally______

26. Is your biological father:

right handed______ left handed______

ambidextrous_____ don´t know______

27. Is your biological mother:

right handed______ left handed______

ambidextrous_____ don´t know______

28. Do you have any left-handed blood relatives such as a sibling? yes______ no______

If yes how are they related?______________________________

____

29. Do you have any ambidextrous blood relatives such as a sibling? yes______ no

If yes how are they related?______________________________

____

30. Was your handedness ever changed? yes______ no______

APPENDIX C

Subject Consent Form

The University and those conducting this project subscribe to the ethical conduct of research and to the protection at all times of the interests, comfort, and safety of subjects. This form and the information it contains are given to you for your own protection and full understanding of the procedures, risks and benefits involved. Your signature on this form will signify that you have received the document described below regarding this project, that you have received an adequate opportunity to consider the information in the document, and that you voluntarily agree to participate in the project.

Having been asked by Jeff Sugarman of the Faculty of Education of Simon Fraser University to participate in a research project experiment, I have read procedures specified in the document entitled: Matching Visual Metaphors to Sound

I understand the procedures to be used on this experiment and the personal risks to me in taking part.

I also understand that I may register any complaint I might have about the experiment with the chief researcher named above or with Dr. Robbin Barrow, Director of Graduate Studies, Faculty of Education, Simon Fraser University.

Copies of the results of this study, upon its completion, may be obtained by contacting Jeff Sugarman, Faculty of Education.

I agree to participate by engaging in the procedures outlined in the "Information Sheet For Subjects" during the period and location agreed to.

NAME________________________________

ADDRESS____________________________________

____

SIGNATURE__________________________________

DATE____________

APPENDIX D

Information Sheet For Subjects

This form describes proposed tests involving physical, psychological, or any other invasive testing.

Title of Project: Matching Visual Metaphors to Sound

Thankyou for participating in this experiment. Your involvement is greatly appreciated.

In this study you will be asked to complete a brief questionnaire concerning your musical training and experience, and your handedness and the handedness of your immediate family. Following completion of the questionnaire, a listening task will be administered. In this task you will hear sounds presented through headphones. You will be asked to attend to one ear in particular, and match the sound heard in that particular ear to a shape. You are to choose among the four shapes and circle the shape which most resembles the sound you heard.

Your questionnaire and test responses are coded such that anonymity is strictly maintained.

At any time during the experiment should you feel a need to withdraw your participation, please do so.

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