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Brain and Cognition 51 (2003) 102–114

Brain and Cognition

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August Knoblauch and amusia: A nineteenth-century cognitive model of music

Julene K. Johnson[a,*] and Amy B. Graziano[b]

[a] *Department of Neurology, Memory and Aging Center, University of California, San Francisco, 350 Parnassus, Suite 800, San Francisco, CA 94117, USA*

[b] *School of Music, Chapman University, Orange, CA, USA*

Accepted 9 August 2002

Abstract

Early models of human cognition can be traced to nineteenth-century investigations of brain and behavior. Influential neurologists such as Wernicke, Kussmaul, and Lichtheim constructed diagrammatic models to illustrate current theories of cognition. Language was the most commonly studied cognitive function during this time; however, investigators also studied other cognitive functions, such as music and visual processing. While a number of nineteenth-century neurologists made observations about music abilities in aphasic patients, August Knoblauch, a German physician and anatomist, was the first to propose a diagrammatic model of music (1888/1890). He described a detailed cognitive model of music processing, hypothesized the existence of nine disorders of music production and perception, and coined the term "amusia." Knoblauch's model is the earliest cognitive model of music and is largely unrecognized as an important part of the history of neurology, neuropsychology, and music cognition.

Keywords: Amusia; Diagram-makers; History; Music cognition; Lichtheim; Kussmaul; Aphasia; Note deafness; Note blindness

1. Introduction

The nineteenth-century was an important time for exploring relationships between brain and behavior. Several disciplines related to brain and behavior emerged during this time, including psychology, psychoacoustics, neurophysiology, and neurology. Of these fields, neurology was the one most focused on the anatomic localization of specific cognitive functions (see Brazier, 1988; Clarke & Jacyna, 1987 for reviews). Investigators carefully observed patients to study the effects of brain damage on various cognitive functions and then speculated about potential underlying neural circuitry. Language was, by far, the most commonly studied cognitive function. The study of aphasia, an acquired impairment of language abilities after brain damage, dominated the field of neurology in the mid- to late-nineteenth

* Corresponding author. Fax: +415-476-4800.
E-mail address: jkj@itsa.ucsf.edu (J.K. Johnson).

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doi:10.1016/S0278-2626(02)00527-4

century. These early studies led to the development of methods for investigating the neural basis of behavior (Benson, 1979; Benton & Joynt, 1960; Doody, 1993).

One strategy used by nineteenth-century neurologists to describe cognitive processes involved the construction of diagrammatic models. While some diagrams were designed after careful observation of many patients, other models were designed first and then tested using patients. A common construction of these models involved the use of "centers" and "pathways." Baginsky, Spamer, Charcot, Wernicke, Lichtheim, and Ballet were among the first diagram-makers (Moutier, 1908). Several modern authors consider these diagrams to be early information processing models (Morton, 1984; Shallice, 1988) and precursors to modern theories of cognition (Jarema, 1993).

While the majority of nineteenth-century models focused on language, other cognitive functions such as visual perception (Lissauer, 1890) and music (Knoblauch, 1888, 1890) were also modeled. The initial interest in non-language cognitive abilities appears to have grown out of a desire to explore the relationship between language and other cognitive abilities in patients with aphasia. Investigators were also interested in understanding relative impairments and preservations of various cognitive functions. In the case of music, they were interested in understanding how language could be produced while singing a song text but not in spontaneous speech. These observations were not only important for helping to expand knowledge about language but also for inspiring early theories about the brain and music. It was in this context that the first cognitive model of music was proposed.

2. Precursors to the Knoblauch model

There was not much interest in music as a cognitive function prior to the mid-nineteenth-century. Of the early diagram-makers, *Adolf Kussmaul* (1822–1902) was the first to include music as one component of his language model (see Fig. 1). In 1877, Kussmaul proposed a diagrammatic model of language in a 300-page monograph titled "Die Störungen der Sprache: Versuch einer Pathologie der Sprache" (The disorders of speech: An attempt in the Pathology of Speech) that appeared in the seminal *Cyclopaedia of the Practice of Medicine* in German (Vol. 12) and English translation (Vol. 14). After addressing issues such as the development of language, the use of language to express human thought, and the neurological basis of language and its disorders, Kussmaul described a model that represented the processes involved in the understanding and production of speech.

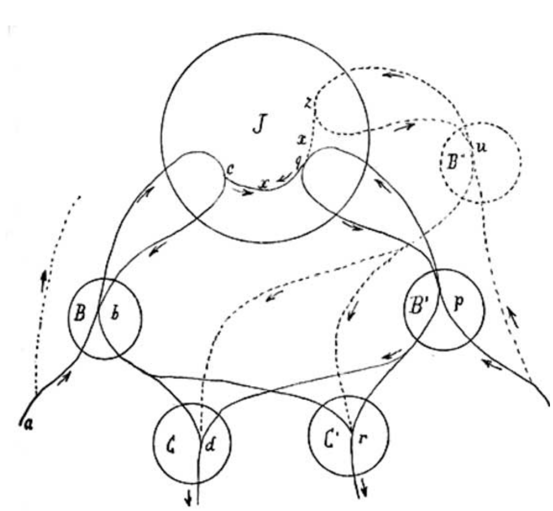

Fig. 1. Kussmaul's (1877a,b) diagrammatic model of language.

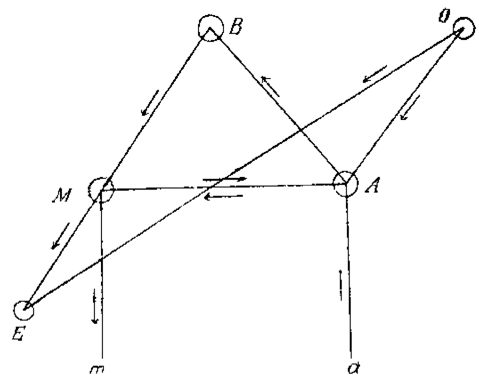

Fig. 2. Lichtheim's (1885a,b) diagrammatic model of language. B is the center for ideas. M is the motor center for words. A is the auditory center for words. E is the motor for writing. O is the visual center for words. a is the auditory nerve, and m is the articulatory mechanism.

In his language model, Kussmaul proposed an afferent pathway from the acoustic nerve (a) for the perception of language (see Fig. 1). He also added a separate pathway for the perception of music that originated from the same pathway (dashed line from acoustic nerve "a"). While describing the function of the auditory nerve, Kussmaul (1877b) states,

> *a* is the acoustic nerve, *o* the optic. Each of these nerves is seen to divide into two branches, one of which, however, is indicated only by points for sake of clearness.—*a b c b d* is the collective acoustic motor track for spoken speech, *o p q p r* the optic motor track for written speech. The adjoining punctuated lines and circles are intended to indicate that still other tracks lead from the nerves of sense through other image-centers to the center for conceptions; the acoustic nerve, e.g., also conveys melodies, and delivers musical ideas and the sound attributes of object-images (song: nightingale) (p. 780).

Kussmaul, therefore, suggested that the auditory nerve functions as a pathway from the sensory organ (ear) to the center for conceptions (where concepts are understood). Although he described a pathway for the auditory perception of music along the auditory nerve, Kussmaul did not connect this pathway with any other part of his model. Thus, he did not predict what parts of his language model, if any, would process music information.

During the 1870s and 1880s, other prominent neurologists also developed diagrammatic models of language, although the processing of music was not included as a component. In particular, *Carl Wernicke* (1848–1905), one of the most important neurologists of this time, proposed a language model in 1874. Eleven years later in 1885, *Ludwig Lichtheim* (1845–1928) made slight alterations to Wernicke's model. Lichtheim (1885a,b) identified five centers and their respective connecting pathways (see Fig. 2) and predicted the existence of seven types of language impairments. Lichtheim's model continues to have influence on modern theories (Graves, 1997; Jarema, 1993; Shallice, 1988), but not without considerable debate (Head, 1926; Henderson, 1992; Laubstein, 1993).

3. Knoblauchs cognitive model of music

Three years after Lichtheim published his model, August Knoblauch (1836–1919), a largely unknown German physician and anatomist, proposed the first cognitive model of music (see Fig. 2). It is difficult to determine how Knoblauch formulated his initial ideas about music. Few historical accounts of Knoblauch's life or career exist. In the late 1800s, Knoblauch worked with Wilhelm H. Erb (1840–1921) in the

Asylum for the Insane at the University of Heidelberg. Erb, an influential physician during the time, emphasized the systematic evaluation of patients and wrote extensively about neurology during his career (McHenry, 1969). In Erb's clinic, Knoblauch observed a patient with motor aphasia who could sing a song text although she was unable to either recite or verbalize the same words in speech. Knoblauch was also aware of several earlier descriptions of music abilities in aphasic patients that were documented by other prominent neurologists such as Charcot, Bernard, Bouillaud, Brown-Séquard, Hallopeau, and Grasset in France and Proust, Steinthal, and Finkelnburg in Germany. He also referred to observations by Gowers and Hughlings Jackson in England. These earlier descriptions, however, were essentially only brief comments about music.

In a paper that appeared in both German (1888) and English translation (1890), Knoblauch combined his observations of the patient in Erb's clinic with observations from the other authors mentioned above to propose a comprehensive diagrammatic model of music processing. He outlined the rationale for the development of his music model, stating:

> In any attempt to explain such a condition, the mode of production of musical tones by the human voice has to be bourne in mind, as well as the arrangement of the commisural paths connecting the cortical spheres for mental representation of sounds with the motor centres of phonation. The mode of combination of the tones produced by phonation, with the sounds emitted by the ordinary action of the muscular apparatus of articulation and respiration, has also to be considered. And further, for the sake of completeness, attention has to be given to the perception of musical tones and its symbols, and to the paths from the sense organs to the higher centres. By this method an idea of the centres and conducting paths in the brain which subserve the perception and production of musical tones and their symbols can be obtained, bearing a close analogy, as was to be expected a priori, to the corresponding centres and conducting paths connected with human language. Further, an attempt has been made by the help of Lichtheim's diagram, to design a scheme from which we could theoretically derive a number of disorders of the musical capacity (1890, p. 317).

Thus, Knoblauch felt that a model of music processing should incorporate multiple music abilities. In addition to the reading and writing of music notation, he considered the production and perception of music to be important components of a model. He also differentiated between input (i.e., sensory organs) and output processes (i.e., phonation, articulation, and respiration) in addition to higher levels of processing.

Knoblauch utilized Lichtheim's diagrammatic model of language (1885a, 1885b) as a template for constructing his own model. Like Lichtheim, he used centers and pathways to represent the components of his music model (see Fig. 2). Also like Lichtheim, Knoblauch felt that the centers and pathways were associated with specific brain structures. The fact that Knoblauch's model was based on early language models suggests that these early ideas about music processing were closely related to ideas about language as a cognitive system.

Apart from his 1888/1890 papers in German and English, it does not appear that Knoblauch wrote any further manuscripts regarding his cognitive model of music. Around 1900–1901 Knoblauch became the director of the city sanitarium in Frankfurt am Main. In Frankfurt, he lectured about neurological disorders and published his lectures in a book titled *Klinik und Atlas der chronischen Krankheiten des Zentralnervensystems* (1909). In this book, he made only a brief reference to his music model (p. 381). He later wrote a chapter on neuroanatomy in *Die allgemeine Chirurgie der Gehirnkrankheiten* (1914) that also included a chapter by Korbinian Brodmann, the prominent neuroanatomist who developed Brodmann's areas. Surprisingly, it was Brodmann, and not Knoblauch, who wrote about music impairments in this later book.

In addition to creating the first diagrammatic model of music, Knoblauch hypothesized the existence of nine disorders of music production and perception that could occur with damage to different parts of the model. To describe the patterns, he coined the term "amusia" and was among the first to use other terms (e.g., tone deafness, note blindness), which were subsequently used by later researchers (Henschen, 1920; McHenry, 1969; Wertheim, 1969). What follows is a description of Knoblauch's model and his nine music disorders.

4. Centers and pathways of Knoblauchs diagrammatic model

As discussed above, Knoblauch drew upon existing diagrammatic models of language that used centers (nodes) and connecting pathways. Nineteenth-century German diagram-makers generally agreed that the centers represented areas in the brain that stored memories, while the pathways represented the functional connections between the centers and images (e.g., information exchange) (Doody, 1993; Kussmaul, 1877a,b; Lichtheim, 1885a,b). Lichtheim (1885b) explained that the centers and pathways are created during the development of language:

> The schema is founded upon the phenomena of the acquisition of language by imitation, as observed in the child, and upon the reflex arc which this process presupposes. The child becomes possessed, by this means, of auditory memories of words (auditory word-representations) as well as of motor memories of co-ordinated movements (motor word-representations). We may call "centre of auditory images" and "centre of motor images," respectively, the parts of the brain where these memories are fixed (p. 435).

Knoblauch uses this quotation in his papers, which would indicate that he believed that music centers and pathways are also created during the early development of music abilities.

Similar to other nineteenth-century diagrams, the centers in Knoblauch's model perform different functions. For example, some centers receive input from the periphery (such as from the auditory nerve); other centers connect with output organs (e.g., the organs for writing, organs for articulation). Depending on their connections, the centers and pathways are involved in different levels of processing (i.e., sensory level, higher centers, output level). Knoblauch felt that his model included all centers and pathways necessary and sufficient for perception and production of music.

Knoblauch identified five centers involved in music processing (Fig. 3). The three primary centers include the auditory center for tones (A′), motor center for tones (M′), and the idea center (B). The remaining two centers are involved with the visual system (O′) and the motor system for writing (E′). For the most part, the centers are modality specific and process only music information. The one exception is the idea center, which is modality non-specific and processes multiple types of information.

The *auditory center for tones* (A′) (*Tonklangbildcentrum*) receives acoustic input ("acoustic impressions") from the auditory nerve (*a*) and is involved in the perception of musical tones. The auditory center for tones is modality specific in that it only receives information relating to music and not other auditory information such as speech. Knoblauch notes that A′ corresponds to Lichtheim's auditory center for speech (A), which receives speech input from the same auditory nerve (a). Knoblauch, however, does not provide a detailed description about the operations of the auditory center for tones; he may have assumed that music information is processed in a similar way to language but in a different center (A′ versus A). The afferent connection between the auditory nerve (a) and the auditory center for tones (A′) is referred to as a *Reflex arc*. The term "reflex arc" was used by Lichtheim (1885a,b) and others to represent the view that the first speech movements are reflex movements that, in turn, form the initial connections between centers and ultimately form memories (or stores).

The *motor center for tones* (M′) (*Tonbewegungsbildcentrum*) stores the motor representations involved in music production (e.g., singing, writing notation). This

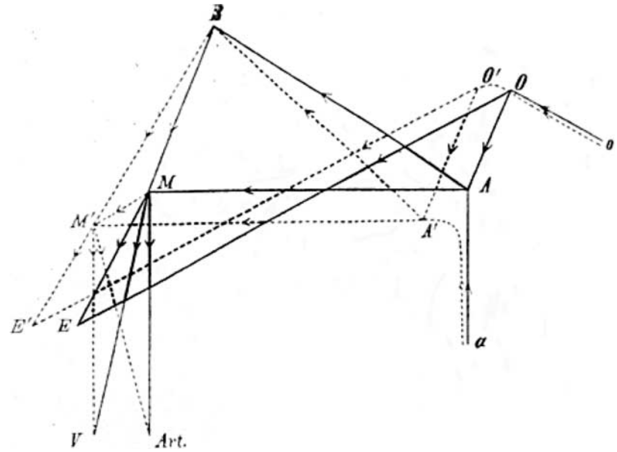

Fig. 3. Knoblauch (1888, 1890) diagrammatic model of music (dashed lines) overlaid onto Lichtheim (1885a,b) diagrammatic model of language (solid lines). B is the center for ideas. M′ is the motor center for tones. A′ is the auditory center for tones. E′ is the motor center for writing music notation. O′ is the visual center for reading music notation. a is the auditory nerve, and V and Art. are the articulatory mechanisms.

center also has an analogous center in Lichtheim's model that is called the motor center for speech (M), where motor memories of language movements (learned during development) are stored.

Music information is analyzed and comprehended in the *Center for Ideas* (B) (*Bildungsstätte der Begriffe*). The idea center is the only modality non-specific center in the model and is involved in the higher level processing of all types of information, not just music information. The center for ideas in Knoblauch's model is identical to Lichtheim's idea center where concepts are formed. Other diagram-makers, such as Kussmaul, Spamer, and Baginsky, also included a center for ideas in their models. The fact that both music and linguistic information share a common idea center implies that Knoblauch believed both cognitive functions involve higher level processing. For musical processing, the idea center is required for: (1) the comprehension of tones and notation and (2) voluntary singing and writing of music notation. It was commonly believed that the idea center was widely distributed throughout the brain. Lichtheim (1885b) explains:

> Though in the diagram, B is represented as a sort of centre for the elaboration of concepts, this has been done for simplicity's sake; with most writers, I do not consider the function to be localised in one spot of the brain, but rather to result from the combined action of the whole iusensorial sphere (p. 477).

The *visual center for notes* (O′) (*optisches Notenbildcentrum*) receives input from the eyes via the optic nerve (o) and allows for the reading of music notation. It is interesting that there is not a direct connection between the visual center for notes and the idea center. For comprehension of music notation, the visual center for notes connects with the idea center through the auditory center for tones (O′–A′–B). A similar pattern occurs with reading words in Lichtheim's model. According to Lichtheim, the visual center for letters connects with the idea center through the auditory center for words (O–A–B) during comprehension of written language.

Knoblauch proposes two additional centers that are involved in singing. While the *Phonation Center* (V) (*Stimmbildungscentrum*) is involved with the formation of the tones by the voice, the *Articulation Center* (Art.) (*Articulationscentrum*) facilitates the formation of words during singing. The articulation center and the phonation center are both stimulated by the motor center for tones (M′). When singing a song without a text, the pathway B–M′–V is activated. However, when singing a song with

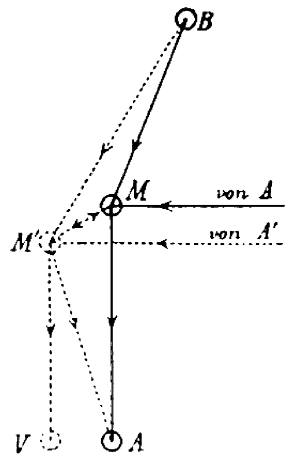

Fig. 4. Interraction of Knoblauch's and Lichtheim's diagrammatic model while singing a song with a text. The motor center for tones (M′) is connected with the motor center for speech (M).

a text, the motor center for speech (M) from Lichtheim's language model is also activated (see Fig. 4). Knoblauch explains how a song is sung with a text:

> In singing a melody with its verbal accompaniment, motor word-representations are produced by the auditory centre for speech, and motor tone representations by the auditory center for tones. The articulation centre being stimulated from the motor center for tones in singing a melody with words, motor word-representations are produced in the motor centre for tones, i.e., the conducting path MM′ must be established. In this path the motor representations of the words of a song are intimately associated with the motor representations of its melody and vise versa (1890, p. 328).

Thus, it is only in singing with a text that the music network interacts with the language model. It appears from Knoblauch's schematic that the connection between the motor center for tones and the motor center for speech is bi-directional, thereby implying that the music and language centers have to cooperate to produce a song with a text.

Finally, the *motor center for writing music notation* (E′) (*Notenschriftbildcentrum)* is activated when an individual copies music notation, writes a melody to dictation, or spontaneously writes down a melody (see Fig. 3). The motor center for writing (E) is the analogous center in Lichtheim's model. These centers are not described in detail by either Knoblauch or Lichtheim.

In summary, Knoblauch evidently felt that music processing is similar to language processing in terms of the number of centers and pathways. However, the centers and pathways for music, although parallel, are for the most part distinct from those involved in language processing. The two exceptions are the motor center for speech, involved in singing the text of a song, and the idea center. It is also clear from Knoblauch's model that he felt music processing involved multiple levels, multiple processing units, was highly interconnected, and most importantly, involved the idea center where concepts are formed. This is further evidence that Knoblauch conceived of music as a higher level, cognitive process.

5. Disorders of music perception and production

In addition to outlining the specific centers and pathways involved in music processing, Knoblauch hypothesized the existence of nine disorders that could occur if specific parts of the network were damaged. Similar to other work in aphasia at the time, Knoblauch classified music impairments into motor (production) or sensory (perception) disorders. More specifically, Knoblauch coined the term "*amusia*" (*Amusie*) to refer to motor impairments. Although Knoblauch used the term amusia to describe a specific disorder resulting from lesions to the motor center for tones (M′), subsequent authors utilized the term amusia in a more general sense (e.g., Benton, 1977; Edgren, 1895; Feutchwanger, 1930; Henschen, 1920; Jellenik, 1956; Wertheim, 1969; Marin & Perry, 1999). To classify sensory disorders, Knoblauch used the terms "*note deafness*" (*Tontaubheit*) and "*note blindness*" (*Notenblindheit*). Grant Allan (1878) was the first to use the term "note deafness"; however, the origins of "note blindness" have not yet been determined. These terms more or less correspond to aphasia, word deafness, and word blindness, which were common terms used for categorizing language disorders (Lecours, Tainturier, & Boeglin, 1988).

In order to determine what part of the network was damaged, Knoblauch felt that it was important to assess both the perception and production of music. He states:

> In examining aphasic patients in regard to their faculty of volitional singing, of repeating melodies or singing notes, it will be necessary to note especially whether the patient can sing only the melody or whether he is able also to articulate words of the text when singing the melody. Especially must we examine him with a view to ascertain whether he has retained or lost the faculty to adapt any set of words to a voluntarily chosen melody, and whether he can articulate them in singing (1890, p. 340).

Knoblauch was the first to suggest a systematic and standard assessment of music abilities, which involved both the perception and production of music. These abilities are almost identical in structure to what Lichtheim proposed in the language domain (see Table 1). While the successful execution of several of these abilities (i.e., volitional singing, repeating tones or melodies) presumably would not require prior training in music, others require a significant amount of music training (i.e., the ability to sing from music notation, write a melody to dictation, and understand written notes).

According to Knoblauch, a careful examination of these abilities would facilitate the determination of the lesion site and identify the specific disorder. Interestingly, his model predicted that focal damage would not globally impair music abilities but instead would have a selective effect depending on which part of the network was disrupted. Two of the nine disorders were associated with damage to centers, while the remaining seven were a consequence of damage to the pathways or connections between the centers. The following sections describe each disorder in detail.

5.1. Lesion to M′

A lesion to the motor center for tones (M') results in "*amusia*" (*Amusie*) (see Fig. 3). Because singing always involves the motor center for tones, the ability to sing in any context (i.e., spontaneous singing, singing from music notation, singing of

Table 1
Comparison of language abilities assessed in Lichtheim's (1885a,b) model and music abilities assessed in Knoblauch's (1888, 1890) model

Lichtheim		Knoblauch	
Volitional speech	B–M–m	Volitional singing	B–M′–v–Art.
Word repetiion	a–A–M–m	Tone/melody repetition	a–A′–M′–v–Art.
Read aloud	O–A–M–m	Sing from music notation	o–O–A′–M′–v–Art.
Volitional writing	B–M–E	Volitional writing of notes	B–M′–E′
Write to dictation	a–A–M–E	Write to dictation	a–A′–M′–E′
Understand words	a–A–B	Understand tones	a–A′–B
Understand written	O–A–B	Understand written notes	o–O′–A′–B
Copy words	O–E	Copy notes	o–O′–E′

notes, and repeating notes and melodies) will be impaired. Because the voluntary writing of notes and writing to dictation are both routed through the motor center for tones (i.e., B–M′–E′ and a–A′–M′–E′), these abilities will also be impaired after damage to M′. In contrast, the comprehension of tones and written notes, and the copying of music notation would remain preserved because these functions do not involve M′.

5.2. Lesion to A′

A lesion in the auditory center for tones (A′) is predicted to disrupt the comprehension of aural and written music (i.e., understanding tones or written notation, writing notes to dictation, repeating tones or melodies, or singing from music notation) and results in *note deafness* (*Tontaubheit*). A disruption to this center should result in the perception of "discordant tones and false intervals." In contrast, the ability to copy notes, spontaneously write music notation, and sing would remain intact because the auditory center for tones is not involved in these functions.

5.3. Interruption between A′ and M′

An interruption in the pathway between the auditory and motor center for tones (A′–M′) is hypothesized to result in an impairment in the ability to sing the correct notes (i.e., voluntary singing, singing from notation, or repeating notes or melodies), which is called *paramusia* (*Paramusie*). Although the ability to sing remains intact, the notes that are sung are described as being "discordant tones" and "false intervals." Knoblauch describes a case with Broca's aphasia who was unable to produce correct pitches while singing a familiar song. However, the patient was able to sing the correct rhythmic patterns and was aware of the melodic mistakes (Kast, 1885). Because of the involvement of both A′ and M′ in writing music notation, damage to this pathway should also impair the ability to write music notation either spontaneously or to dictation, which is called *paragraphia* (*Paragraphie*). In contrast, the ability to comprehend notes and written notation, as well as copy music notation, should remain intact.

5.4. Interruption between B and M′

An interruption in the pathway between the center for concepts and the motor center for tones (B–M′) is hypothesized to disrupt abilities that require initiation from the center for concepts. Knoblauch, therefore, proposes that damage to the B–M′ pathway should result in impairments in volitional singing and volitional writing of music notation. All other music skills should remain preserved because they do not involve this pathway. Knoblauch recognized similar cases described by Behier, Charcot, and Bouillaud.

5.5. Interruption between M′ and V

Damage to the pathway between the motor center for tones and the peripheral articulatory system involved in forming tones (M′–V) leads to an impairment in singing tones (i.e., volitional singing, repeating tones or melodies, or singing notes). In contrast, the comprehension of melodies and music notation remain intact. Knoblauch cites a case by Proust (1872), who describes a musician with aphasia who was unable to sing a melody but could read and write notes as well as compose and recognize melodies.

5.6. Interruption between a and A′

If the pathway between the peripheral auditory system and the auditory center for tones (a–A′) is disrupted, the comprehension of tones, the ability to repeat melodies, and the ability to write a melody to dictation are impaired.

5.7. Interruption between A′ and B

Because the A′–B pathway is involved in the comprehension of music, an interruption in the pathway between the auditory center for tones and the center for concepts should result in difficulty understanding tones or written music. In contrast, the ability to sing in all contexts remains intact. The ability to write notes after hearing a melody and to copy notes is also preserved.

5.8. Interruption between O′ and A′

An interruption between the visual center for notes and the auditory center for tones (O′–A′) should result in an deficit in comprehending music notation or singing from music notation (*note blindness*). Because the copying of music notation bypasses the auditory center for tones, this ability remains preserved.

5.9. Interruption between M and M′

The final impairment described by Knoblauch is unique in that it is the only scenario in which his music network interacts with Lichtheim's language model (see Fig. 4). Knoblauch makes a distinction between singing with and without a text. In order to sing a melody without words, the pathway from the center for ideas (B), to the motor center for tones (M′) is activated. In contrast, the singing of a song with a text activates the motor center for tones (M′) *and* the motor center for speech (M), as well as the pathway B–M–M′–V. Thus, when the pathway between the motor center for speech and the motor center for tones (M–M′) is disrupted, the ability to sing a text with a melody is impaired. However, if the motor center for speech (M) is damaged but the pathway B–M–M′–V remains intact, it is still possible to sing a text.

It is interesting that Knoblauch does not propose clinical symptoms resulting from lesions to the center for ideas (B), the visual center for notes (O′), or the writing center (E′). He also acknowledges the possibility of simultaneous disruption of several pathways that would result in a number of complicated syndromes. Although he carefully tests his model with one case, Knoblauch notes that the model was constructed primarily to direct the attention of current researchers to possible disruptions of music after brain damage:

> Such a fact gives rise to the hope that the scheme…will indicate to observers how those rare cases are to be explained, and also direct their attention to those points which should be carefully observed (1890, p. 318).

6. Localization of music

Knoblauch does not elaborate about possible underlying neural structures that may be involved in music perception and production. However, he does draw upon Lichtheim's predictions for language and suggests that the music centers and pathways should be close to the language areas. Knoblauch explains:

> We shall not attempt to localize the supposed centres in the brain or to represent the paths leading from and to those centres. It is evident that the auditory centre for tones must be

> very near the auditory centre for speech, and the motor center for tones will be very near the motor center for speech, the former in the superior temporo-spenoidal convolution, the latter in the third frontal convolution of the left hemisphere. As to the visual centre for notes, and the motor centre for the writing of notes, these, we believe, will be found occupying the same place as the visual centre for letters and the motor centre for the writing of letters. The phonation center will be situated near the articulation centre, the site of which is, however, still undecided (1890, p. 339).

Specifically, Knoblauch predicts that the auditory center for tones is near the "superior temporo-sphenoidal convolution" (superior temporal lobe), and the motor center for tones is near the "left third frontal convolution" (Broca's area). In a more general sense, Knoblauch proposed that music was a left hemisphere function. The localization of music from an anatomical perspective continued through the beginning of the twentieth century and culminated in an extensive clinical and anatomical review of over 300 cases by Henschen (1920). More recent studies in the last 10–15 years have shown that the brain areas involved in music processing are generally distinct from language networks. Furthermore, music networks appear to be widely distributed networks across both hemispheres, depending on what music function is tested (see Marin & Perry, 1999; Peretz, 2001 for reviews).

7. Discussion

Knoblauch's diagrammatic model of music (1888, 1890) holds an important place in the history of neurology, neuropsychology, and music cognition for several reasons. Overall, the development of Knoblauch's model confirms the significant presence of music in nineteenth-century discussions about brain and behavior. Although not as numerous as discussions about language, prominent neurologists such as Charcot, Bernard, Brown-Séquard, Gowers, and Hughlings Jackson discussed music in aphasic patients. It appears that the initial interest in music developed out of a desire to understand the patterns of preserved and impaired cognitive abilities in patients with aphasia.

It was Knoblauch who first discussed music as a cognitive system. In Knoblauch's model, the perception and production of music is achieved through a complex network of interconnected centers and pathways. These pathways and centers are involved in different levels of processing. Like other diagram-makers of the mid to late nineteenth century, Knoblauch felt that music processing involved an interaction among sensory processes, intermediate centers that store memories (e.g., auditory center for tones, motor center for tones), and conceptual thought (i.e., the idea center). Thus, music could only be perceived or produced following the multi-level flow of information through the network. In particular, the fact that music interacts with the idea center suggests that Knoblauch considered music to be a higher level cognitive process, similar to language. The idea that music could be studied in terms of its cognitive structure subsequently became an important aspect of research in the fields of neurology, neuropsychology, and music cognition.

Like other diagram-makers, Knoblauch supported the idea that brain damage can affect cognitive abilities in a selective fashion, leaving some abilities intact while damaging others. The selective patterns of preserved and impaired functions were predicted based on interruptions to various parts of the model. For these reasons, the nineteenth-century diagrammatic models are considered to be early models of cognition that share similarities with current methods for representing cognitive processes (Jarema, 1993; Morton, 1984; Shallice, 1988). Knoblauch's model anticipated several late twentieth-century ideas about music and brain; for example, current theories continue to support the idea that music processing is generally distinct from other cognitive systems and is supported by music-specific brain networks (see Peretz, 2001 for review).

In addition to the idea of studying music as a cognitive system, Knoblauch's classification of music disorders had a significant effect on subsequent descriptions of music impairments. Shortly after Knoblauch's publication, several more extensive manuscripts devoted to discussing music abilities in aphasia were published by Wallaschek (1891), Brazier (1892) and Edgren (1895). Knoblauch's classification scheme was discussed in these and other articles. Most importantly, the term "amusia" became a standard term to designate an impairment in music abilities after brain damage. As discussed earlier, Knoblauch used the term to classify a specific impairment in the production of music, while subsequent authors have used the term to denote a general impairment in music abilities. Today, although rarely attributed to Knoblauch, amusia remains a standard term in neurology and neuropsychology (e.g., Adams, Victor, & Ropper, 1997; Heilman & Valenstein, 1993).

Finally, Knoblauch's contributions are also important because he recommended a standard assessment of musical abilities that would help document the nature of the music impairments and also localize the lesion within his model. Although he did not specify how to assess musical skills, he did provide a detailed description of what specific skills should be assessed. Since several of these abilities require prior musical training, Knoblauch implied that his assessment and disorders are specific to musicians. To the best of our knowledge, this is the first discussion of a standard test battery for musical skills. However, Knoblauch's recommendation for a standard assessment was not followed after the publication of his 1888/1890 papers. It was not until Seashore developed his measures of musical talent (Seashore, 1919) that standardized tests were implemented as part of the assessment of music abilities.

In summary, Knoblauch made four significant contributions to the neurology of music: (1) his model has historical significance as the earliest cognitive model of music, (2) he coined the term "amusia," (3) he proposed a classification scheme for disorders of music perception and production, and (4) he recommended a standard assessment of music abilities. It is for these reasons that Knoblauch deserves recognition as an important figure during a pivotal time in the study of music, brain, and cognition.

Acknowledgments

The authors would like to thank the University of California libraries (SRLF, NRLF). This project was supported by a Grant-in-Aid from the Office of the Provost, Chapman University (ABG). The authors would also like to thank Hellmuth Petsche, M.D., Michael Graziano, Ph.D., and Mark Ring, Ph.D. for helpful comments.

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