HOW THE GUITAR SHAPES US: Part I

By Amy Brandon and David Westwood

Guitar movements are complex. Using the language of motor control, the movements we make in performance can be described as *bimanual* (both hands active simultaneously), extremely *fine* (with small changes, as little as a millimetre, having a potentially profound effect on timbre), as well as *uncoupled* and *asymmetric* (each hand needing to accomplish different tasks). During performance a guitarist's arms will shift positions, which adds to the complexity of the bimanual coordination task.[1] The movements can also be very fast and in some cases require significant pressure, up to 0.897kg of force (12 psi) for a single note.[2] Asymmetric movements are particularly challenging from a control perspective, as can be seen in the child's game of trying to tap the top of one's head while moving the other hand in a circle over the stomach. The body tends to naturally revert back into a more stable coordination pattern of in-phase, similar, and symmetric movements, and the pattern breaks down. The movements of a guitar performance are similarly somewhat unnatural to the body, and thus complex from a motor control standpoint. The movements in guitar performance differ in significant ways from other musical instruments, such as piano or strings.[3] For piano players, bimanual movements are fast and precise but are relatively symmetrical, with both hands essentially executing the same types of vectors (downwards key presses) in tandem. In string performances, the degree of individuated finger control differs greatly between the left and right hands, which is unlike guitar. So, what is known about the control of movement in skilled guitarists? Relatively little. Whereas some significant neuroimaging and focal dystonia studies have been conducted exclusively with guitarists,[4] the vast majority of research on motor control in musicians is conducted on piano and string performers. This article provides a brief overview of research from fields of motor control, neuroscience, and musicology to develop a surface sketch of the ways expert guitar performance leaves its traces in the body, mind, and brain.

I. Adaptations to the Body and Brain

Neuroplasticity in musicians

EEG and neuroimaging techniques provide tools for studying the brains of living musicians. Magnetic resonance imaging (MRI), voxel-based morphometry (VBM), and diffusion tensor imaging can measure physical brain structures, while functional magnetic resonance imaging (fMRI) can be used to infer levels and patterns of brain activity by association with variation in blood oxygen levels. EEG (electroencephalogram) sensors on the skin of the scalp can also be used to measure patterns of low-level electrical activity generated by the brain (brain waves). Numerous neuroimaging studies have used musicians (most frequently pianists and violinists) as subjects, as they are seen as ideal candidates for neuroplasticity research.[5] These studies have consistently shown that these musicians have structural brain adaptations different from non-musicians. Structural changes in the brains of musicians have been noted in the hand-motor area, auditory areas, white matter tracts, corpus callosum, grey matter volume (neurons, dendrites) in motor areas, and areas associated with higher-order cognitive processes such as attention, memory, and language.[6] The specific plastic changes seen in expert musicians are thought to be related to the years-long process of musical training they undergo to achieve expertise.[7] While most neuroplastic changes usually occur over long periods, certain changes can occur in hours or days (new synapses or dendrites), or weeks (enlargement of neurons and myelin sheets).[8] Musicians who began training early (around age 7) during the sensitive period of brain development are seen as even more likely to have significant plastic changes,[9] referred to as metaplasticity,[10] which can enhance future musical skill acquisition. The level of movement precision and stability in expert musicians can be observed in studies such as Baader (2005), which showed that left-hand movements of violinists were extremely consistent from trial to trial.[11] High levels of consistency and precision in expert movement is known more generally across motor control studies but also indicated in guitar-specific movement studies such as Wright (2012), which found that expert guitarists showed less preparatory brain activity (via EEG) prior to onset of musical movement than beginners.[12]

Interaction between guitar and body

Embodied cognition argues that cognitive structures and processes (like attention, memory, vision, motor control) reflect the ways in which the body is used to interact with the world. In particular, musical theories of embodied cognition argue that a musician's performance is mediated by the instrument they play. This offers the concept that the interaction between instrument and body (called

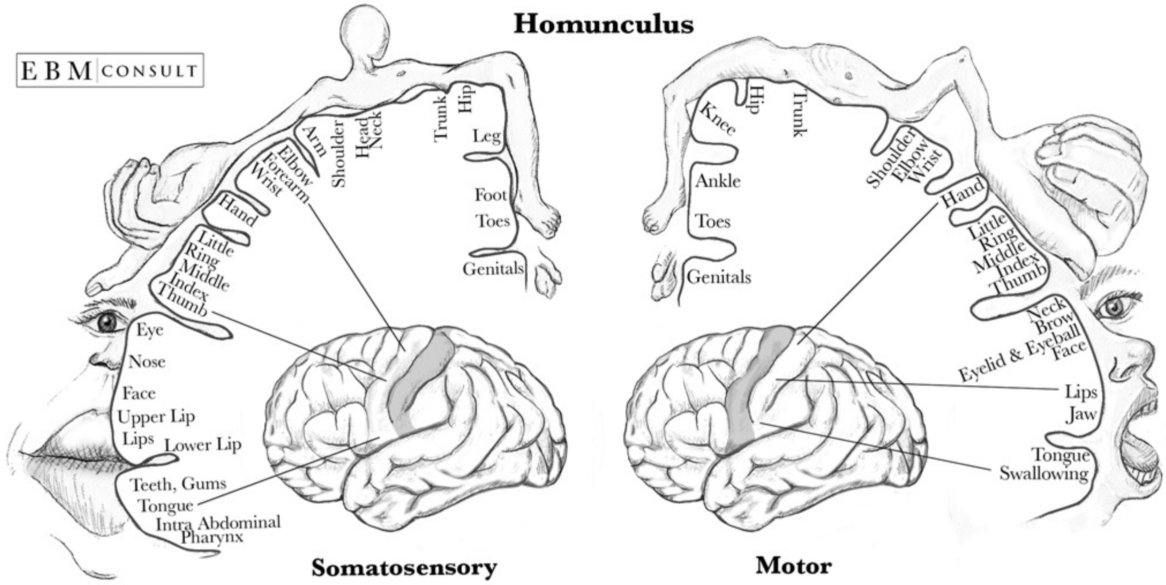

Figure 1: Brain areas representing sensory and motor control of the hand.
Image provided by EBM Consult.

affordances), influences and shapes the music that is eventually performed.[13] Qualitative research in jazz and blues guitar improvisation offers some indication of this, particularly how the affordances of the fretboard, tuning system, and span of hands is evident in motor patterning of jazz and blues guitar improvisations. A particular example of this is the tendency for guitarists and other fretted instrumentalists to navigate the fretboard using perceptual or visuomotor feedforward processes, regardless of musical style or presence of formal training. In essence, expert guitarists frequently describe the fretboard as "lighting up," or overlaid with graphic or visual shapes, outlining chords or scale patterns, which assist with navigation, memorization, improvisation, and performance.[14] While the music of the guitar can be seen as being shaped by the affordances of the instrument, the body also adapts to the affordances of the guitar, shaping itself around the instrument. One noticeable physical change in string performers is a lengthening of the left-hand fingers in comparison with those of the right hand.[15] In guitarists, measurements of pinch strength are also noticeably asymmetric between the hands.[16] Other ergonomic changes are made more consciously and specifically; for example, the right-hand nails can be seen as a type of specialized body modification. Footstools and other accoutrements could be viewed as ergonomic adaptations designed to ease use and reduce error when operating with the "system" of a guitar.[17] Other bodily changes are less outwardly visible but may show in level of performance ability, namely finger independence or dexterity.

Our hands are primarily specialized for grasping objects, not for guitar performance. Some muscles and tendons in the hand can be partially fused, so that movement in one finger will result in partial movement of the other.[18] In addition, up to fifty percent of the population can have hands that differ from the standard anatomical configuration of muscles and tendons, with certain ones being missing or modified.[19] While the brain areas representing the sensory and motor control of the hand are prominent (**Figure 1**), areas controlling individual muscles can be scattered and often overlap.[20] In addition, some studies have shown synchronization in the motor neurons controlling individual finger muscles, which may also lead to co-activation.[21] This means that when you want to move one finger, a second finger may be activated automatically. Thus, increased finger individuation can be seen as one of the primary adaptations for expert guitar performance. Indeed, increased levels of finger individuation have been studied in musicians (particularly pianists) and found to be directly related to musical training. For example, Kang (2013) found that inter-digital cortical connections in musicians were particularly strong in comparison to non-musicians.[22] Furuya (2014) was able to replicate this process on a small scale by training musically naive individuals in piano practice; they gained greater ring- and little-finger independence over just four days of training.[23]

Inhibition and coordination

One of the ways the brain may adapt to increase finger individuation in guitarists is by the mechanism of surround inhibition. Surround inhibition (SI) is a physiological mechanism that shapes fine motor control through the capacity of excited or active neurons to reduce the activity of the surrounding neurons and suppress movement in neighboring muscles.[24] Essentially, SI leads to greater control over individual finger movements by suppressing unwanted movements in neighboring fingers. Inhibition is also involved in coordinating movements between the two hands. In general, bimanual coordination arises from a network of brain and cortico-spinal areas.[25] In particular, adaptations for complex two-handed movements in musicians can be observed in physical changes to the brain area known as the corpus callosum (the fibrous white matter that connects the two brain hemispheres. See **Figure 2**), which enables communication between the motor areas in different hemispheres.[26] The corpus callosum is also theorized as the conduit through which one hemisphere may inhibit the other, preventing unwanted or mirror movements (interhemispheric inhibition or IHI).[27] When a unimanual task is performed (such as reaching out with one hand to pick up a coffee mug), interhemispheric inhibition is part of the process that prevents the mirroring of the movement (mirror activity or MA) and reaching for the mug with both hands. Although certain TMS (transcranial magnetic stimulation) studies such as Ridding et al. (2000) and Nordstrom and Butler (2002) have indicated that musicians (pianists, guitarists, violinists, harpists) have *reduced* IHI, more recent studies have found that musicians tend to have *increased* interhemispheric inhibition.[28]

Figure 2: The corpus callosum.

Increased IHI could be viewed as reflecting an increased need to limit mirror activity in a musician accustomed to performing complex bimanual movements. Of particular note, many music-related plastic changes seem to be instrument-specific, perhaps because of different requirements for bimanual coordination.[29] Instrument specificity in music cognition is not a new concept, as differing plastic changes have also been noted in motor recruitment and other areas of the brain related to music cognition.[30] However, as guitarists are rarely studied in music cognition, it is not clear whether these types of instrument-specific plastic changes may extend to them. Given the additional complexity of bimanual movement and coordination for guitarists due to the nature of the movements involved, looking at IHI in the context of guitar performance could be a fruitful focus of future research.

The types of movements we associate with expert guitarists are initially restrained by the natural features of our bodies and brains. Our hands and arms structurally are limited in things like range of motion, finger individuation, muscle strength, and speed. Overcoming these limitations physically changes our bodies and brains. Our fingers may lengthen, our muscles develop. We consciously adapt ergonomically to the guitar (nails, footstool), and our brains enhance dexterity and finger individuation by increasing levels of surround and interhemispheric inhibition. However, this is not the whole picture of motor control in guitar performance. In addition to overcoming constraints through adapting our bodies to the guitar, guitarists must also impose constraints in order to achieve stable bimanual movements. As Panagiotis Kassavetis writes in his 2009 thesis on surround inhibition and motor control, "Individuation of fingers increases the degrees of freedom of hand movements and therefore increases the range of activities that can be performed, but it also increases the computational capacity necessary to accurately control them."[31]

II. Cognition and Motor Control

Overcoming and imposing constraints

The need to impose constraints on movement arises from the degrees-of-freedom problem that is inherent in the motor control of the human body.[32] This concept, also known as the motor-equivalence phenomenon, speaks to the fact that the body can be used in many different ways to accomplish the same task. For example, there are many combinations of muscles, joints, and trajectories that can be used to pick up a glass, yet humans seem to choose stereotyped—and efficient—patterns of reaching and grasping movements to complete the task, implying that the nervous system automatically selects an optimal combination of motor commands from the almost infinite range of possibilities. To put this in a classical guitar context, there are numerous ways in which *i* can pluck string 1. The finger and wrist joints may be angled in slightly different ways. An example of this would be Ida Presti's right-hand technique, in which the strings are struck by the right-hand edge of the nail instead of the left. In addition, the shoulder and elbow can be angled or positioned in different ways depending on context. Small changes in guitar position and footstool height will alter arm and hand position. Different techniques such as free stroke and rest stroke alter finger positioning, among other potential changes. While motor equivalence is seen as a beneficial evolutionary adaptation, one which imposes no constraints on the numerous movement possibilities, it nonetheless increases the complexity of effectively executing a task such as a guitar performance.

Motor programs, sensory feedback, and motor learning

As movements are practiced, stability and precision improve over time to an optimal state through the process of motor learning. The effortless way an expert might play a C chord in first position, versus the struggles of a beginner, would be an example of this process. In learning and consolidating new movements, sensory feedback is seen as of significant importance, both in guiding the novel movement and in correcting errors. Also, sensory feedback is seen as key in models of learning, and the process of storing, searching, and executing learned patterns of movement, i.e., Schmidt's schema theory (1975), Fitts and Posner's three stages of learning (1964), and Adams' closed-loop model (1971). In general, sensory feedback is seen to play a role in the abstract internal representations of movements (generalized motor programs) and models of movement patterns (recall and recognition schema) that enable the development of expertise.[33] Examples of sensory feedback in a guitar context could be seeing how your hand looks on the fretboard (visual), how it feels to play a chord (somatosensory or kinaesthetic), or what a particular chord sounds like (auditory). However, once novel musical movements become consolidated and automatic, the exact role of sensory feedback in controlling musical movement becomes less clear. Part of this relates to the fact that, in fast musical movements, visual, auditory, and sensory feedback may reach the brain more slowly than the movements they are connected with.[34] There are many models (forward, inverse) of how sensory feedback is used to update movements. However, this is outside the scope of this article beyond mentioning that how the brain anticipates and reacts to sensory feedback in ongoing musical movements is complex and not completely understood.

Sensory feedback in online control of musical movement

The lack of clarity regarding the role of sensory feedback in controlling consolidated musical movements is present in the research on motor control in both improvised and memorized music. Some researchers such as Pressing (1988) apply theories of motor programming to improvisation, arguing that the need for visual feedback in musicians diminishes with time and expertise.[35] This perspective is echoed by improvisation researchers Norgaard (2016) and Dean (2014), who found that improvisations in pianists and guitarists can become more automatic in stressful or difficult situations.[36] However, current theories of motor control such as Proteau's (1992) specificity of practice indicate that reliance on visual feedback actually *increases* with expertise for reaching and aiming tasks.[37] The role of auditory feedback in consolidated musical movements is similarly unclear. Significant work on motor control in music has emphasized the role of auditory feedback in controlling musical movements.[38] However, some empirical research indicates that auditory and even sensory feedback may be unnecessary for the successful execution of expert musical movements.[39] For example, a violin study, Fritz (2014), found that disrupting the visual, auditory, and somatosensory feedback of violinists did not impact their ability to gauge the quality of the violin they used.[40] Finney (1997) and Finney and Palmer (2003) found that playing a muted piano in a sight-reading task did not seem to influence the resulting piano performance.[41] Repp (1999) drew similar but slightly modified conclusions, saying that auditory feedback was essential for piano pedaling and some expressiveness.[42] Related research, such as the neuroimaging studies of James et al. (2014), found decreased grey matter in the sensorimotor areas of musicians.[43] Some evidence also points to this same phenomenon in a guitar context. In a pilot study examining visual, sensory, and auditory feedback in guitar performance, Brandon (2017, n=1) found that, as with Finney and Palmer (2003), a complete absence of auditory feedback resulted in a performance statistically indistinguishable from the control.[44]

One explanation given for this contradictory evidence regarding auditory and visual feedback is the strong crossmodal connections between the motor and sensory systems of musicians.[45] Because of their intensive training, musicians are seen as having superior multisensory integration, meaning that they can process and respond to sensory stimuli better than non-musicians.[46] Theoretically, these strong audiomotor and visuomotor connections may explain this phenomenon, as auditory feedback (the expected sound from playing a piano chord) may be generated internally if the actual feedback is perturbed or missing. Alternatively, sensorimotor or kinaesthetic feedback may be sufficient to allow for error correction in music performance. While pianists have significant audiomotor connectivity, in guitarists the evidence points more strongly to a visuomotor encoding of movement. Qualitative research indicates that some guitarists more heavily use spatial and visual information to guide motor movements.[47] Crump (2012) also found that expert guitarists were more likely to recognize chords from photographs rather than auditory or graphical representations.[48] Examining the role of feedback in a guitar-specific context seems to indicate that visuomotor connectivity in particular may play a key role in both the initial learning and online control of complex guitar movement sequences.

Visual encoding of movement sequences

The visual encoding of guitar movement patterns might be a factor in the memorization of long movement sequences, such as an entire piece.[49] Theories of motor control hold that most voluntary movements are made up of the serial or simultaneous execution of small motor units called motor primitives.[50] Although the exact segmentation of human movement can be difficult to define,[51] a guitar example of a single motor primitive might be a single note or chord. Complex serial or simultaneous sequences of motor primitives are the basis for the fluid movements we associate with guitar performance. The supplementary motor area (SMA) is seen as a locus of coding complex movement sequences. However, different patterns of brain activation will be seen depending on whether the musician is a beginner or a professional, and whether he or she is learning a piece, performing a piece from memory, or sight-reading. The encoding of complex movement sequences generally happens in stages. Novel movement patterns are first learned quickly, and then consolidated by the brain over a period of six to eight hours after the activity has concluded.[52] Experts will learn more quickly than novices, having domain-specific memory for musical and motor patterns related to performance.[53] Subsequent practice sessions offer significant but diminishing returns on improvement.[54] However, it is during these subsequent repetitions of the motor sequence that new synaptic connections and cortical map reorganization occur.[55] Once learned, movement sequences are bound together and encoded using internal symbols or graphic representation that can be quite conceptual and abstract, and influenced by the environment the memorization occurs in.[56] Because complex sequences are abstractly coded into internal hierarchies for future recall,[57] it is sometimes difficult for musicians to begin portions of a memorized piece anywhere but a few set points. This can be shown in memory studies of musicians where the most retained information is the music at structural points, when retained information is stronger at the beginning of phrases but reduces in accuracy towards the middle of structural elements.[58] After learning and memorizing a piece, musicians also often continue to overlearn a piece and practice it beyond the stage necessary for effortless performance. However, it is not clear what function overlearning affords.[59]

III. Conclusion

The underlying complexity of expert guitar movements is clear to both audiences who applaud them and artists who understand the years of practice behind their effortlessness. Music cognition studies have shown how the bodies and brains of musicians come to adapt to allow these complex tasks, but more research must be done to examine whether there are neuroplastic changes specific to the guitar. One potential area of research is in interhemispheric inhibition and the corpus callosum, the brain structure that coordinates movement between the two hands, as this structure shows signs of instrument-specific plasticity.[60] As well as overcoming natural constraints, the body and brains of expert guitarists also impose constraints on movements in order to stabilize them through the process of motor programming. Questions remain regarding the exact role of sensory feedback in expert musical movements, as there is contradictory evidence regarding the reduced need for auditory and somatosensory feedback in consolidated musical movements, which is not consistent with established theories of motor control. However, one potential explanation for this inconsistency is the remarkable connectivity between the auditory and motor systems in pianists, while in a guitar context the evidence also suggests a particularly strong role for visual feedback and visuomotor encoding, which extends to assist in the coding of the complex movement sequences required for expert guitar performance.

The second half of this article will appear in the next issue of Soundboard.

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Holding degrees in jazz guitar performance and composition, Amy Brandon is currently completing an interdisciplinary PhD in music cognition at Dalhousie University in Halifax, Nova Scotia. She has performed internationally (Canada, USA, Brazil, Australia, New Zealand, UK) and at several experimental music festivals. In addition to performing and academic work, she has written contemporary guitar, chamber, orchestral, and acousmatic pieces, with premieres at National Sawdust (NYC), Chorus Festival (London, UK), GroundSwell (CAN), Cerisy Castle (France), Guitar Alla Grande (CAN), 21C (Toronto) and the Mise-En Festival (NYC). For more information, visit: amybrandon.ca.

David Westwood studied kinesiology and psychology at the University of Waterloo, completing an MA and PhD in the area of behavioral neuroscience, with a focus on vision and the control of arm movements in skilled tasks. His NSERC-funded research laboratory explores the sensory, cognitive, and motor mechanisms that underlie performance of skilled tasks. A Professor of Kinesiology at Dalhousie University, Dr. Westwood teaches courses in Motor Control and Learning, and the Neural Basis of Sensory and Motor Function. He has also dabbled in music as an alto saxophone player.

HOW THE GUITAR SHAPES US, PART 2: The dual-notation environment

By Amy Brandon

Part 1 of this article appeared in the previous issue of Soundboard.

In between a sheet of notation and the sound it represents lies a complex network of brain activity and physical movements.[1] Notation can be seen as a *visuomotor transformation*, a type of tool for the establishment, coding, and cueing of motor sequences, resulting in a performance. Where the guitar is unique is that in addition to traditional notation, which primarily consists of music symbols (pitch, rhythm), it also has a second language of *movement notation* such as chord charts, scale patterns, and tablature, which indicate finger positioning on the fretboard in a highly visual and graphic manner. While musical movement notation is primarily connected to guitar and lute (with the exceptions of more obscure tablatures such as organ and harmonica), it also appears in other art forms. Dance in particular has used forms of movement notation since the 17th century, with the dominant language being *Labanotation* (**Figure 1**). To dancers, Labanotation is seen as having significant value as a pedagogical, archival, and analytical tool.[2] However, in the guitar world, the merits of movement notation outside a historical context such as lute transcriptions are not clear, and the benefits and drawbacks are often the subject of significant debate among guitarists and pedagogues.[3] Regardless, the persistent popularity of tablature, chord, and scale charts in common pedagogical materials remains a key feature of guitar culture,[4] and it is not well understood exactly why the guitar uniquely retains movement notation in pedagogical and performance practice.

I. What is music notation in motor-control?

Notation is a set of visual symbols that establishes, encodes, and triggers sequences of movement in guitarists. Sight-reading music notation involves distinct brain areas adjacent to, but not precisely discrete from, areas used for language. **Figure 2** indicates the areas that overlap and are active in both language processing and score-reading. Like language, score reading appears to be primarily lateralized in the left hemisphere, and the network of brain areas noted to be active during score-reading are the supramarginal

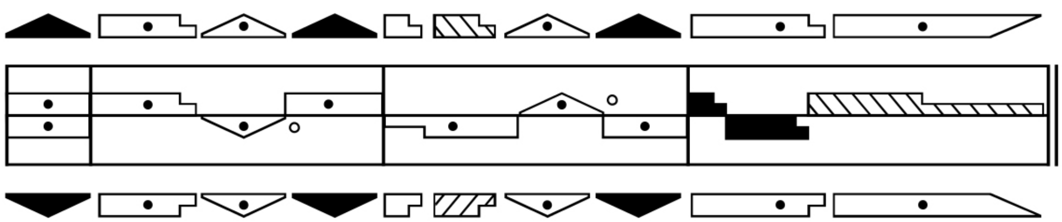

Figure 1: Labanotation

Brain areas involved in score-reading (Schön, 2002; Dekker, 2015)			
Brain Area	**Active in score-reading**	**Active in Language-reading**	**Possible Role**
Supramarginal Gyrus	√	√	Motor intention, particular fingerings
Superior Parietal Cortex	√		Active while performing only, neuroplastic, poss. visuo-spatial processing
Interparietal Sulcus	√		Sensorimotor integration, fine motor movements
Fusiform Gyrus (Inferior Temporal Gyrus)	√	√	Neuroplastic, rhythm-reading, note recognition
Left Superior Frontal Gyrus	√		Working memory
Middle Frontal Gyrus	√	√	Working memory

Figure 2: Brain areas

gyrus, superior parietal cortex, intraparietal sulcus (IPS), fusiform gyrus, and left superior frontal gyrus (**Figure 3**). Because these areas are also understood to be involved in more general tasks (visuospatial navigation, object recognition) it would be expected that these areas would be active in the process of sight-reading a score (looking at the score, recognizing the symbols, spatially orienting the symbols, translating them to movements).[5] However, some areas are theorized to be particularly involved in the task of translating scores into motor cues, including the supramarginal gyrus and the intraparietal sulcus. For example, Stewart (2005) found that the supramarginal gyrus only becomes active during score-reading in musically naïve participants after three months of instrumental training.[6] The intraparietal sulcus is another area found to be active only in score-reading but not in processing language or numbers.[7] In particular the intraparietal sulcus is also thought to relate to sensorimotor integration, fine motor control, and visuospatial processing.[8]

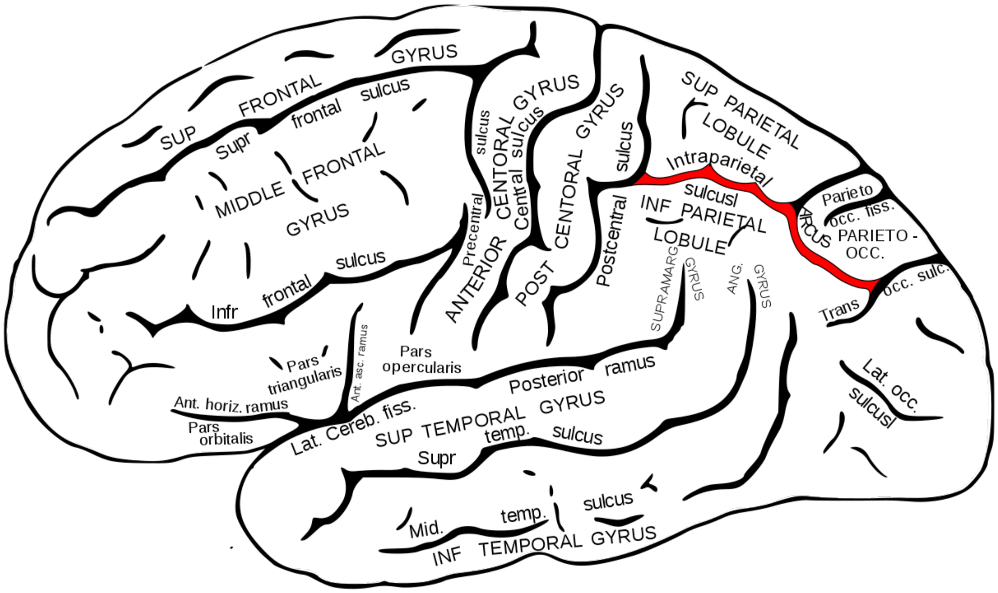

Figure 3: Brain areas: score reading

II. Different activation patterns for different types of notation = different performances?

As cognitive scientist Jiajie Zhang wrote regarding diagrammatical representations and graphs, "The form of a representation determines what information can be perceived, what processes can be activated, and what structures can be discovered from the specific representation."[9] Whether different notation would truly alter how the music is perceived by the performer, it may be that different types of notation do recruit different brain areas in a similar manner to how different patterns of activation will often be seen depending on whether the musician is a beginner or a professional, and whether he or she is performing a piece from memory or sight-reading (**Figure 4**). For example, Roux (2007) indicates that reading note names such as "A, B, G, G, F" as letters will use different brain areas than seeing the same notes as notation.[10] However, this differentiation is to be expected as the processing of language and score-reading do not activate precisely the same areas of the brain. Whether a

Specialized Patterns of Activation in Musicians (Pianists)	
	More activation in ...
Beginner or Amateur - Learning	Pre-Motor Area - initial stages of learning (Toni et al. 1998) Supplementary Motor Area Visual Cortex - Ventral stream: visual object information for grasping Cerebellum - forming of novel motor sequences (Larsell & Jansen, 1967; Schlaug, 2001; Hutchinson et al. 2003) Basal Ganglia - formation of novel motor sequences (Hund-Georgiadis & von Cramon, 1999)
Professional Musician – Learning or Memorizing a New Piece	Basal Ganglia – formation of novel motor sequences
Musician Performing from Memory	Supplementary Motor Area
Musician Performing from Score or External Stimulus	Superior Parietal Area - integrating sensory information in motor planning Visual Cortex - Dorsal stream: visual cue triggering movement
Watching another perform your instrument	Primary Motor Cortex
Imagining Performing	Pre-Motor Area (Watson, 2006)

Figure 4: Brain activation

different pattern of brain area activation would be seen in the reading of traditional notation versus tablature is not currently known, and may be an avenue for future research. However, it is reasonable to theorize that an expert guitarist reading the same piece of music in two forms, tablature and staff notation, might show slightly different patterns of brain activation, given the distinctly different nature of the two written systems. This prompts the question: If different notations are indeed processed differently, would there also be a measurable impact on performance or interpretation?

III. Guitar's dual-notation environment

If notation can be seen as "symbols that translate to movement," and if different types of symbols are seen as possibly shaping the musical meaning that is perceived,[11] then the persistent dual-notation environment of the guitar (traditional notation and tablature) becomes an interesting facet of guitar performance. The relative popularity of traditional notation and tablature has waxed and waned since the origins of the modern guitar in the mid-18th century. Initially, tablature was the only notation for both lute and early guitar, prior to 1750. After this date, printed guitar music transitioned through several types of single-stemmed and multi-stemmed traditional notation, paralleling the development of the modern Spanish guitar through the mid 19th century. Beginning in the 20th century, tablature reappeared, primarily in jazz and popular music.[12]

Paul Sparks, in *The Guitar and Its Music*, addresses this transitional stage from tablature to notation in the mid-18th century.[13] For a certain period both forms were in use in pedagogical materials, with the author of the *Encyclopédie* of 1757 waxing lyrical about tablature in his introduction, saying that "this method, although ancient, is conserved for this instrument through the ease that it gives to the gracefulness of the hand, the arrangements of the fingers, the beauty of sound, harmony, and the facility in execution."[14] However, as notation began to be introduced for the guitar around 1750 (primarily in France) condemnations of tablature also appeared. Italian musician and composer Giacomo Merchi, who claimed to have introduced notation to the guitar in Paris, wrote that he "withdrew the guitar from the servitude which it had relative to tablature."[15] In other publications he was vociferous in his condemnation of tablature, writing in *Le Guide des écoliers de guitarre…* of 1761:

> I believe that it is an abuse, and I shall prove it by the following reasons. Those who only know tablature cannot truly play, and accompany only by routine and without balance. Those who use tablature successfully were good musicians before they learned it, and had no need of it. These reasons have led me to suppress its use in this work. If someone objects that it is necessary to mark the [left hand] positions, I would respond that the violin, the cello, etc. never use tablature, and that the guitar has less need [to do so] than them because it has frets. As with other instruments, all that is necessary for success is the application of a good method; I have neglected nothing to render mine easy, clear, and agreeable.[16]

This debate of notation versus tablature returned after the turn of the 20th century with the advent of blues and jazz. Publishers of American Banjo, Mandolin and Guitar (BMG) magazines often derided the tablature used to teach blues, folk, and jazz music as "The Simpleton Method,"[17] whereas Dave Berend, publisher and ghost-writer of the first methodology of jazz guitar by Eddie Lang in 1936, offered a vigorous defense of tablature, pointing out the peculiarities of physical performance in jazz guitar as an obstacle and the chord chart as the solution:

> Many teachers hesitate to use the idea of playing from chord names and diagrams because they regard it as a new, modern conception which is largely a makeshift to obviate learning to read music. As a matter of fact it is perhaps the oldest form of guitar notation. It dates back to the wandering Troubadours and Minstrels of the Middle Ages. It was then known as ENTABLATURE. Music notation was in its infancy and this was the only means they had of transcribing the chords used on their guitars for accompaniment to their singing. Much of their music cannot be reproduced from these diagrams because the tuning of their guitars and lutes is unknown, since it antedated the tempered scale and other modern conceptions. Since the notes on the staff do not follow the placing of the fingers on the guitar fingerboard as logically as for the right hand of the piano or harp (high-note-high finger) the diagram idea is the best means of transferring the chords from the printed page to the instrument.[18]

Moving into the 21st century, the controversy has not abated in any way (as any brief Google or YouTube search indicates), with many guitarists, researchers, and pedagogues of all guitar styles having strong opinions on which one works best for themselves and their students.[19] Each argument follows similar lines to those in the 18th century: tablature helps with spatial navigation of the fretboard while traditional notation leads to a more musical performance.

IV. Inadequacy of both notations

This multi-century debate surrounding the relative merits of tablature versus traditional notation is understandable, as notation and tablature essentially transmit completely different information, even if they both notate the same piece. Movement notation such as tablature or chord charts provides no absolute pitch information, phrasing, dynamics, or any other musical information. They are purely spatial orientation devices, profoundly unmusical, but yet provide an instant access route to musical movement in a guitar context. Classical guitar notation is quite the opposite in this regard—much less, or zero, information about spatial fretboard navigation but greater kinaesthetic information such as exact left- and right-hand fingering information, and musical information such as dynamics, pitch, and phrasing. The deficiencies in both notational forms must be supplied by an experienced teacher, who can add missing technical, musical, or spatial information not present in the score. These deficiencies in how we notate music for the guitar, combined with the fact that most young guitar students practice primarily alone from method books prior to university,[20] may be why it is common for university guitar students to experience significant difficulties with sight-reading and technical tasks when reaching university-level studies in jazz and classical guitar.[21]

V. Spatial navigation and guitar

It is easy to understand the advantages of traditional notation. It provides a direct understanding of the intended result of the music. Yet, tablature and the apparent need to communicate the spatial navigation aspects of guitar performance persist. This begs the question: What is it about the guitar, specifically, that results in the need or desire for a *spatial* movement notation? After all, like Merchi indicated in the 18th century, there are other instruments that are navigated spatially (piano, harp, strings) that do not employ spatial notation. So why? It's not clear. However, it could be argued that the uniquely complex layout of the guitar fretboard is a possible genesis point for why spatial movement notation endures. The "labyrinthine"[22] layout of the fretboard may present unique cognitive challenges to learning and executing complex motor sequences, and graphically expressed spatial navigation eases this complexity by providing visual patterns with which to bind or encode complex fine motor sequences.

VI. Unique complexity of the fretboard

As jazz guitarist Mick Goodrick wrote in his method *The Advancing Guitarist*, on the guitar "the average note has 2.8 locations and 9.2 possible fingerings."[23] So, in order to sight-read traditional notation, the guitarist must first memorize (or partially memorize) the locations of seventy-two individual notes, some of which are doubled or tripled, and whose disposition does not conform to any simple pattern or layout for ease of memorization. The guitar tuning system of fourths and a third was initially designed to allow chords to be played with ease, which results in a non-symmetrical layout unlike that of the harp, piano, or strings. Hence, finger mechanics concerning which of the four fingers plays which note in any given context (often there are multiple options) is almost exclusively left to the performer, compounding the difficulty.[24] So, efficient movement for fast sequences must be planned in advance to ensure proper finger placement, making sight-reading a series of rapid decision-making tasks that may be particularly challenging for beginners. The fretboard is also a blank grid, not color-coded and directional as with the piano. The language used to describe guitar navigation is also biomechanically counterintuitive, as notes ascend and descend in pitch contrary to the direction of hand motion. As your hand moves "up" the fretboard, not only is it actually moving toward the floor, but pitches can ascend or descend depending on string choice. As James Sallis notes in *The Guitar Players*, "The guitar is, physically, a difficult instrument; to get past its cumbersomeness to the music inside requires considerable application. Things other musicians take for granted—legato playing, dynamics, even simple reading—can become awesome problems on the guitar."

VI. Conclusion: Fretboard and cognition

The non-sequential nature of the guitar fretboard could be significant from a music cognition perspective as well, as some studies indicate that our brains process melodic information better when it is mapped sequentially or congruently to the physical device being used, where keys or buttons are mapped as left to right equals low to high.[26] Therefore, it could be argued that the guitar fretboard, with its doubled notes, irregular layout of pitches, multiple fingering options, and blank-grid appearance presents a particularly unique cognitive challenge to performers, which may encourage or invite a spatial approach in both conception and notation, regardless of style.

Endnotes

[1] See "How the Guitar Shapes Us: Part 1," *Soundboard* 45, no. 1 (March 2019): 39–45.

[2] Raoul-Auger Feuillet, John Weaver, and Mr Isaac, *Orchesography: Or, The Art of Dancing by Characters and Demonstrative Figures...* (London, 1715); János Fügedi, "Movement Cognition and Dance Notation," *Studia Musicologica Academiae Scientiarum Hungaricae* 44, nos. 3–4 (2003): 399.

[3] Numerous theses and articles have touched on this subject, particularly with reference to training beginners or undergraduate students; e.g., Colin Elmer, "Replacing Patterns: Towards a Revision of Guitar Fretboard Pedagogy" (MM thesis, Univ. of Adelaide, 2009), 4. Other examples include Ward (2011), 59–60; Beaumont (2015), 45–46; Stickford (2003), 66; Balistreri (1995), 3; Berard (1998), 31. (See the complete bibliography for this article on the GFA website at Publications » Soundboard Magazine » Files 45.2.)

[4] Walter Lance Beaumont, "Bringing It All Together: Formal and Informal Learning in a University Guitar Class" (DMA diss., Boston Univ., 2015), 38–43.

[5] E. A. Dekker, "The Neural Localization of Musical Score Reading" (Master thesis, Utrecht Univ., 2015), 20–21, 6.

[6] Lauren Stewart, "A Neurocognitive Approach to Music Reading," *Annals of the New York Academy of Sciences* 1060, no. 1 (2005): 385; Matthew FS Rushworth, Amanda Ellison, and Vincent Walsh, "Complementary Localization and Lateralization of Orienting and Motor Attention," *Nature Neuroscience* 4, no. 6 (2001): 656; Dekker, 10, 13.

[7] Daniele Schön et al., "An fMRI Study of Music Sight-Reading," *Neuroreport* 13, no. 17 (2002): 2288; Franck-Emmanuel Roux et al., "When "abegg" Is Read and ("A, B, E, G, G") Is Not: A Cortical Stimulation Study of Musical Score Reading," *Journal of Neurosurgery* 106, no. 6 (2007): 1025.

[8] L. A. Jäncke et al., "The Role of the Inferior Parietal Cortex in Linking the Tactile Perception and Manual Construction of Object Shapes," *Cerebral Cortex* 11, no. 2 (2001): 114; Ferdinand Binkofski et al., "Human Anterior Intraparietal Area Subserves Prehension: A Combined Lesion and Functional MRI Activation Study," *Neurology* 50, no. 5 (1998): 1253; Olivier Simon et al., "Topographical Layout of Hand, Eye, Calculation, and Language-Related Areas in the Human Parietal Lobe," *Neuron* 33, no. 3 (2002): 475.

[9] Jiajie Zhang, "The Nature of External Representations in Problem Solving," *Cognitive Science* 21, no. 2 (1997): 179.

[10] Roux, 1017–27.

[11] John Baily and Peter Driver, "Spatio-Motor Thinking in Playing Folk Blues Guitar," *The World of Music* 34, no. 3 (1992): 57–71.

[12] Erik Stenstadvold , "The Evolution of Guitar Notation, 1750–1830," *Soundboard* 31 (2006): 11–29; James Tyler and Paul Sparks, *The Guitar and Its Music: From the Renaissance to the Classical Era* (Oxford Univ. Press, 2002), 200–01; Eddie Lang and Dave Berend, *Eddie Lang's Fingerboard Harmony for Guitar* (New York: Robbins, 1936).

[13] Tyler and Sparks, "Part III: The Origins of the Classical Guitar."

[14] *Encyclopédie*, ed. Denis Diderot (Paris: 1757), ii, 1012; quoted in Tyler and Sparks, 200.

[15] Giacomo Merchi, *Traité des agrémens de la musique exécutés sur la guitarre…oeuvre XXXVe* (Paris: l'auteur, 1777; facs. repr. Geneva: Minkoff, 1981); quoted in Tyler and Sparks, 201.

[16] Giacomo Merchi, *Le Guide des écoliers de guitarre…Ve livre de guitarre, oeuvreVIIe* (Paris: l'auteur, 1761; facs. repr. Geneva: Minkoff, 1981); quoted in Tyler and Sparks, 201.

[17] Jeffrey Noonan, *The Guitar in America: Victorian Era to Jazz Age* (Univ. Press of Mississippi, 2008), 40.

[18] Lang and Berend, 62.

[19] See note 3.

[20] Stefan Degner, Andreas C. Lehmann, and Hans Gruber, "Expert Learning in the Domain of Jazz Guitar Music," in *Proceedings of the 5th Triennial ESCOM Conference*, 387; Michael Berard, "Production and Evaluation of a Self-Instructional Method for Teaching Jazz Guitar" (MA thesis, Concordia Univ., 1998), 61.

[21] Harold James Odegard, "The Plight of Jazz Guitar Students and Proposed Solutions" (MM thesis, Univ. of Texas at El Paso, 2004): 1–2; Jeffrey James McFadden, "Fretboard Harmony for University Study: Method and Historical Context" (DMA diss., Univ. of Toronto, 2010), 52.

[22] McFadden, 52.

[23] Mick Goodrick, *The Advancing Guitarist: Applying Guitar Concepts & Techniques* (Milwaukee: Hal Leonard, 1987), 93.

[24] Rocco Matone, "An Integral Concept for Jazz Guitar Improvisation." (MM thesis, California State Univ., 2005): 1.

[25] James Sallis, *The Guitar Players: One Instrument and Its Masters in American Music* (Lincoln: Univ. of Nebraska Press, 1982), 186.

[26] Marianne A. Stephan et al., "Crossmodal Encoding of Motor Sequence Memories," *Psychological Research* 79, no. 2 (2015): 318; see also Hoffmann, Sebald & Stocker, 2001; Stocker, Sebald & Hoffmann, 2003; Rusconi, Kwan, Giordano, Umilta & Butterworth, 2005; Keller & Koch, 2008.

Holding degrees in jazz guitar performance and composition, Amy Brandon is currently completing an interdisciplinary PhD in music cognition at Dalhousie University in Halifax, Nova Scotia. She has performed internationally (Canada, USA, Brazil, Australia, New Zealand, UK) and at several experimental music festivals. In addition to performing and academic work, she has written contemporary guitar, chamber, orchestral, and acousmatic pieces, with premieres at National Sawdust (NYC), Chorus Festival (London, UK), GroundSwell (CAN), Cerisy Castle (France), Guitar Alla Grande (CAN), 21C (Toronto) and the Mise-En Festival (NYC). For more information, visit: amybrandon.ca.