21st-CENTURY BRASS PEDAGOGY: MODERN SCIENTIFIC DISCOVERIES AND THEIR IMPLICATIONS ON CURRENT BRASS PEDAGOGY

by

Jason M. Sulliman

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Doctoral Committee

____
Carl Lenthe, Research Director, Chair

____
Richard Seraphinoff

____
Katy Strand

____
Joey Tartell

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To my son Thaddeus- May you remain ever mindful and seek life's answers to find new questions.

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Preface

This method book is divided into three chapters. Chapter One presents a concise and distilled history of the scientific fields of human movement (kinesiology) and thought (cognition) up through the late nineteenth century with significant contributors being used to illustrate the development of how we believe people move, and think (and ultimately learn).

Chapter Two introduces several different scientific fields of research that developed between the late nineteenth and early twenty-first centuries. This chapter gets a little tricky as several different contributions were happening almost simultaneously from different vantage points and readers with little/no scientific background may be misled into the overly simplistic summation of lumping the methods and viewpoints from these different fields into one large category of 'scientific ideas'. A few significant streams of research and inquiry are presented that suggest specific reconsideration be made in regards to key aspects of brass pedagogy (specifically timing, harmonic context, and embouchure/mouthpiece setting).

In Chapter Three, exercises are presented based on conclusions determined from Chapters One and Two. First, typical and mainstream versions of standard exercises that are found in common method books are presented. They are coupled with a brief description of the evolution of those methods. Second, based on current scientific beliefs, aspects of the exercises that seem contradictory to 21st-century scientific thought are called into question. Lastly, alternative examples of these exercises, in the form of original contributions are presented with explanations as to why they more closely align with current scientific trends. It should be noted that in most cases the repertoire currently utilized by performers and teachers (solos, etudes, excerpts, etc.) is not being challenged here. Instead, the purpose of this method is to offer insight and suggestions as to the way pedagogical methods are administered to better prepare brass players so they may perform whatever repertoire they like.

21st-CENTURY BRASS PEDAGOGY: MODERN SCIENTIFIC DISCOVERIES AND THEIR IMPLICATIONS ON CURRENT BRASS PEDAGOGY

Since the beginning of brass instruments, much of the information utilized to develop a pedagogical framework for teaching and playing these instruments was developed through personal experience, trial and error, and anecdotal teaching through a largely apprenticeship system. Pedagogical ideas were developed from the vantage point of current information viewed through the lens of conventional thought of the time. Several emerging fields of scientific research have contributed to new information that contradicts what was previously viewed as pedagogically stable ideology. This paper summarizes a history of conventional thought towards human learning and movement, provides a brief description of new and emerging fields of scientific inquiry that have been created/enhanced by technological advancements in measurement equipment, and offers several examples of new ways to apply current scientific beliefs towards conventional brass pedagogy in the form of exercises that can replace traditional pedagogical exercises based on outdated information.

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In order to play a brass instrument, one has to move their body. In order to play a brass instrument well, one has to refine their movements through repetition. Throughout the history and development of brass pedagogy, the challenge has never been understanding that if you practice something, you will improve at it. This is a basic idea common to all forms of pedagogy. A more important question is how one should practice in order to maximize the benefits. How should we train our movements to make them better faster? This type of repetition requires careful thought. We need to think in order to move, but how should we think about our movements to maximize efficiency?

The first question that must be answered is where do the two roads of thought and movement meet? What is movement? What is thought? When an arm moves, we call it movement. What about when our lungs expand when we inhale? What about a heartbeat? What about a blood cell traveling within the body or an electrochemical shift during a neurological synapse? What is the smallest movement that is still considered a movement? Where do we delineate what is *thought* and what is *movement*?

For years scientists have been on a quest to identify the exact boundary between thought and movement; when biochemical changes cause an actual physical output. The trail of understanding is a winding and bumpy road to say the least. Current beliefs are a result of previous beliefs combined with examining those beliefs through the lens of current scientific inquiry. By examining the history of movement and learning we can add valuable context to better understand current beliefs and this may enhance the effectiveness of current teaching methods within the 21st-century world of brass pedagogy.

Chapter One: A Brief history of Movement and Learning

To better understand how current pedagogy was developed (and why it might be a little antiquated) we need to have a basic understanding of the history behind current beliefs in movement and learning. By charting out the development of society's beliefs in these areas, we can start to see where major shifts occurred, and where current scientific understanding could have potentially fostered a different path had it been available at the time. Without this background information, some modern theories might only seem semantic as opposed to practical. Our journey must go back to what many scientists consider 'the beginning': Ancient Greece.

Aristotle (384 B.C.-322 B.C.) was the first major scientist/philosopher to develop a plausible explanation for action theory. The backbone of his work rested on four main principles or "causes." Aristotle believed that every action can be explained by identifying the role that these four causes play on each other. By distilling a recipe for action in this manner, any action can be explained (Lindberg, 2010). First, **final cause** is the goal or purpose towards which someone aims. **Formal cause** is that which makes a thing that sort of thing and no other. **Material cause** is the stuff to which it is made. Lastly, **efficient cause** is the force that brings a thing into being.

By way of musical example, the **final** cause could be a melody or phrase that I want to play on my trombone. The **formal** cause could be the specific melody in question. The **material** cause is the trombone itself, and the **efficient** cause is my internalized concept of sound in regards to how the phrase should be played.

Aristotle believed, as did other scientists/philosophers, that nothing, strictly speaking, can move or act on itself. This belief remained largely unchallenged for centuries and created a huge problem that is still debated even by modern scientists. Aristotle's explanation was brilliant. Organisms were simply split into two parts. If we take an example of a lion chasing a gazelle for food, he split the lion into a soul and a body. First, the soul of the lion is the 'unmoved mover" while the body is acted upon by the final cause, being the object of desire. In this case, the gazelle. The gazelle causes the body of the lion to want food, thus the lion moves. Using this logic, Aristotle would have explained my musical scenario by saying that my body is acted on by the final cause (my soul's desire to play the phrase), which causes my body to move and play the phrase (formal cause) utilizing the trombone (material cause).

Modern day cognition has a few sub-disciplines currently supported by well-respected scientists, such as embodied cognition and situated cognition. The premise of embodied cognition stresses the importance of the actual body that an agent or soul is in. Different bodies cause organisms to navigate their environment differently, and thus learning and cognition are constrained by one's own body. For example, an organism with eyes on both sides of its head will view the environment differently. Humans with a single arm will think (consciously and unconsciously) about solving problems or completing tasks in a different manner than two-armed (bi-manual) human beings. In our musical example, my body (including my lungs, arms, embouchure, etc.) will affect how I mentally navigate any musical situation. Someone with bigger lungs, more facile chops, etc. would perceive the same exact situation differently. Situated cognition, on the other hand, stresses the importance of the organism existing in a particular environment, and that environment will shape learning and cognition. An environment can include a broad description such as a school one attends or an ensemble one plays in, but may also refer to the musical environment and harmonic context one is navigating.

With his explanation of the soul being the "unmoved mover," Aristotle summed up both modern-day embodied cognition and situated cognition in one idea. The soul of the agent needs to be embedded within the body of the agent itself (embodied cognition) and the agent needs to be situated within its environment (situated cognition) to truly be understood. Additionally, his focus on voluntary motion or goal-directed behavior was an important component of understanding thought and movement. Aristotle's work remained basically unchallenged for over fifteen hundred years until roughly the end of the medieval era.

The Slow Shift away from Aristotle: Philosophy Driving Experimentation

In the fourteenth century, several mathematicians were responsible for formulating mathematical principles such as the Merton Rule or the Mean Speed Theorem. Thomas Bradwardine (ca. 1290-1349), William Heytesbury (ca. 1313-1372/73), John Dumbleton (ca. 1310-ca. 1349), and Richard Swineshead (f.c. 1340-1354) were all part of the Merton School at Oxford and collectively became known as the *Oxford Calculators* (Sylla, 2011). They are credited with some of the earliest examples of arithmetically discovering how to calculate the speed of motion as well as constant acceleration (Agutter & Wheatley, 2008). Additionally Nicole Oresme (ca. 1320/25-1382) was able to demonstrate similar theorems geometrically. They did so in a way that was contrary to Aristotle's theories of movement, which marks the first written examples of some of Aristotle's ideas being challenged.

The shift away from the writings of Aristotle was a slow, gradual process that took centuries and was experienced over several different layers of information and theories. Even during the seventeenth century, scientists like Rene Descartes (1595-1650) still echoed some of Aristotle's ideas. Descartes used the phrase 'dualism' to explain the mind and body as separate entities with the mind acting on the body. The mind did not need anything to act on it, which kept free will, or goal-directed behavior involved as an important component of action and movement (Baker, Baker & Morris, 2002). For our discussion, Descartes marks the end of the widely accepted philosophical beliefs on movement that aligned with the work of Aristotle. The development of physics and the explanation of movement through physical properties that follows Descartes influenced a shift in scientific thought. The seventeenth century's scientific revolution was largely attributed to Galileo Galilei (1564-1642), Nicolaus Copernicus (1473-1543), Johannes Kepler (1571-1630) and Sir Isaac Newton (1642-1727). This revolution had significant implications related to understanding learning and movement. (Hall, 1954)

It is important to note that the theoretical works of Orseme and the Oxford calculators came before the pioneers of scientific observation. Theories and philosophy will often precede scientific experiment, yet both facets lead to a shift in conventional thought. The end of the medieval era saw the first shift away from some of Aristotle's ideas and though much of this shift has been later supported by research, several by-products emerged that had an adverse effect on brass pedagogy.

Sir Isaac Newton

A problem arose in the seventeenth century with the innovative work of Sir Isaac Newton (1643-1727). Newton developed an equation for gravity and with it he described a deterministic universe with atoms being acted on by predictable and constant forces, such as gravity (Verlinde, 2011). In his theory, things are related to each other only externally. Newton's theory deviated from the way Aristotle explained movement in that Newton's theory implicitly removed formal, material, and final causes from the discussion. Formal cause and material cause were moot under Newton's theory since objects were all made up of the same atomic particles. Final cause was no longer needed to explain movement as objects were acted upon by constant and predictable forces (as opposed to goal-directed behavior).

In addition to devaluing formal, material, and final cause, Newton also moved theories of cognition away from modern-day situated and embodied cognition (Juarrero, 1999). Since measurement equipment at the time was not sophisticated enough to demonstrate the importance of factors such as color, temperature, and friction, these factors were cast aside as ancillary (which was supported by the existing framework of Galileo and his 'inclined planes'(Longair, M.S. 2003). It was easier to investigate by isolating factors, and science progressed to the point where organisms no longer needed to be situated in their environment (or embodied) in order for cognition and movement to be studied and understood. Context and environment were no longer important in science or philosophy and this created a shift in the development of the way scientists examined movement and cognition.

Lastly, Newton managed to remove one of the most important modern-day constraints with the publication of his theories: time. Aristotle's equation for movement theory included arrows that signified a specific direction (→) in order for the equations to make sense. Newton described his theories in a highly deterministic universe of predictably colliding atoms. Given the way in which he described the interactions between physical properties, his theories for motion were calculated with the use of an equal sign (=). By adopting Newtonian principles, the importance of time as a necessary constraint by mathematicians and philosophers slowly disappeared (Juarrero, 1999). By the end of the seventeenth century, three of Aristotle's causes were forgotten, and time and environmental context no longer mattered in theoretical thought or scientific experiments for cognition and movement.

The Industrial Revolution

After the advancements of the seventeenth-century scientific revolution, the industrial revolution caused significant changes to the way scientific principles were shaping society. Increased sophistication of machinery was driving investigation forward as there was a push for more efficient design (manufacturing) as well as more specific means of measuring data (research). This development caused researchers to think differently about physical properties which would go on to influence theories of cognition and movement. Entire branches of scientific inquiry were developed as a result of this major shift in technology.

Classical thermodynamics is a field of study that was developed in the mid-nineteenth century and served as a branch of physics that focused specifically on the transfer of energy (Boltzmann, 1974). It was developed out of necessity for improving the efficiency of the steam engine and utilized findings from scientists like Robert Boyle, who developed Boyle's law in which pressure and volume are inversely proportional in a closed system (Boyle, 1662). Scientists such as Lord William Thomson Kelvin (1824-1907) are credited with making major contributions to the development of the field by explaining the transfer of energy within/between organisms and particles through four basic laws. (Buchdahl, 2009)

The scientific field of thermodynamics provided physical evidence that was helpful in bringing the importance of time back as unidirectional in causal systems of action (echoing the work of Aristotle), however it dealt only with organisms that are closed systems, isolated from their environmental context, and near equilibrium (which made application towards human cognition and movement almost impossible). Though thermodynamics was an important contributor to the development of modern theories of cognition, it did not immediately provide a greater understanding of cognition and action that could be practically applied to actual human movement and behavior. The implications for human cognition and movement were only theoretical (Frank, 2000).

This was a pivotal time in the history of science. Scientists and philosophers (which were sometimes the same individual) were developing what they felt to be a reliable method of investigation. All variables but one were controlled (or ignored) and scientists examined the behavior of that one dependent variable in a series of tests to determine its role in holistic function (Jevons, 1958). This method of investigation was useful at times, especially when investigating physical properties (such as gravity), and seems intuitive when compared to the development in mechanics during the industrial revolution (highly predictable outcomes by changing a single variable within a mechanism such as a steam engine) however it negated the role of the environment acting as a constraint and (at times) also ignored the effects of time as well as embodiment in holistic function. Furthermore the scientific process of examining one variable in isolation overlooked the possibility that variables might act dynamically in context, and those dynamic interactions might create a whole that is different than the sum of its parts (an idea later brought to the fore by Gestalt psychologists) (Wertheimer, 1944). This is a direct result of the shift in thought that began with the scientific revolution of the seventeenth century and was carried further by the technological developments of the industrial revolution. It would create huge problems for the future fields of cognition and kinesiology (human movement) and the effects can still be seen in present-day brass pedagogy with the absence of environmental constraint, time, and dynamic interaction as respected factors of pedagogy itself. Examples of the specific ramifications of these factors will be addressed in Chapters Two and Three.

Darwin and Evolution

In the middle of the nineteenth century, a geologist named Charles Darwin (1809-1882) wrote “On the Origin of Species” which laid out significant evidence for his theory of evolution. According to Darwin, the environment acted as a constraint that organisms would have to successfully navigate. As mutation occurred, certain organisms found advantages within their respective environment and were more successful in reproduction as a byproduct of greater survival. Over several generations mutations would be passed down as genetic traits that caused species to evolve as a direct result of the environment they were situated within. His theory accounted for the mechanism responsible for increasing complexity in biology and returned the importance of context to scientific research by giving the environment a central role in agent selection (Bowler, 2003). Darwin's scientific contributions represent the first time since Newton where the environment is credited as playing a major part in the development of an organism. This was considered a 'course-correction' by modern-day situated and embodied cognitive scientists as evolution was not limited to a physical body, but was believed to have an effect on the way organisms think and move through their respective environment.

Darwin's theories were not immediately accepted as they appeared to contradict classical thermodynamic laws. In classical thermodynamic principles, everything is winding down (entropy) while in Darwin's theory of evolution, things are gaining in complexity (through mutation and evolution). With Darwin's theory, cognition and movement are affected because agents are constrained by the environment and, through this constraint, a constant process of evolution and development would naturally occur as a byproduct. Agents are highly complex because they are descendants from agents that have been the most successful at adapting to their specific environment in how they move and think (Miller & Page, 2009).

As the modern scientific era developed, we can see several moments where research and theories start to reemphasize the importance of time and environmental constraint as major factors in developing thought and action. Thermodynamics revisited the importance of time in causal systems and evolution showcased the importance of environmental constraint in the development of an organism, however, scientific inquiry was becoming a term too broad to represent all of the emerging fields of study.

Chapter Two: The Complexity of the 20th-Century

Examination of physical forces (physics), examination of mental forces (cognition, behaviorism, psychology) and combinations (e.g. psychomotor learning) were starting to follow different ideas and streams of research, and these fields of scientific inquiry were examining different aspects of thought and action through different lenses. It is nearly impossible to both summarize every stream of scientific inquiry with a level of adequate comprehensiveness and present them all in either a cohesive chronological manner or categorically separated in a way that shows both their independent ideas as well as the influence they had on other scientists (and ultimately pedagogy of the current day). Moving forward from this point poses a greater challenge with clearly defined lines of scientific fields. My attempt here is to lay out different contributions in an approximate chronological manner to allow the reader to understand how so many different directions of science all played a role in shaping the way people studied human thought and action, which in turn shaped our current world of brass pedagogy.

Phenomenology

A branch of philosophy known as Phenomenology had developed in the late 19th century, which dealt with human perception and action (Sokolowski, 2000). Franz Brentano (1838-1917) was a German philosopher who championed the idea of cause in a way that resembled the work of Aristotle and contributed to bringing some of Aristotle's ideas back into focus. Brentano separated physical and mental phenomena and believed that every mental act (such as a belief or desire) has an object that was the focus (just as the final cause or the "object of desire" was explained by Aristotle (Føllesdal, 1978). Mental phenomena had meaning only because the mental being was situated within the body that experienced the physical world (rejuvenating both situated and embodied cognition as major components of perception and action). Brentano went further to say that human perception is extremely fallible and perceiving something is different than it actually being true. "Perception is misconception...we can only be sure of our internal perception" (Føllesdal, 1978). Descartes, who also viewed human perception as unreliable, similarly described human perception with his famous phrase, "I think, therefore I am." With sensory information being inaccurate, he believed the only way we exist is through the phenomenon of mental thought (Veitch, 1902).

Carl Stumpf (1848-1936), a student of Brentano, continued to develop the concept of Phenomenology. His work (specifically in music) was aimed at differentiating between perceived stimuli and imagined stimuli. Stumpf believed that human perception, however fallible, must be taken into consideration, which differed from the work of Descartes and Brentano. Further, he argued that imagination and perception must work together in some manner to enable humans to create a holistic understanding of our environment that prioritizes efficiency at the expense of accuracy, thus accounting for inaccuracy of perception (Plomp & Levelt, 1965).

The work of some of Stumpf's students, most notably, Kurt Koffka (1886-1941), Max Wertheimer (1880-1943), and Wolfgang Köhler (1887-1967) would contribute immensely to this end with the development of Gestalt psychology (Ash, 1998).

The Emergence of the Gestaltists

Gestalt psychology is a theory of mind that attempts to explain the way in which people perceive the world through a top-down, self-organizing, and holistic manner. Kurt Koffka, Max Wertheimer, and Wolfgang Köhler each made significant contributions to the development of Gestalt laws of psychology. When the human mind perceives a Gestalt or "whole form", the whole form, as it emerges, becomes different than the sum of its perceived parts (Koffka, 1922). According to the laws of Gestalt psychology, the human brain is a fierce self-organizer, but also has the ability to separate elements and understand them each in their own individualized complexity. One important aspect of Gestalt psychology is the emergence of a whole, which streamlines the information needed to develop a meaningful understanding of the environment. For example, timbre is a complex combination of several different factors of sound that can each be examined, such as pitch onset (Krumansl, 1989), spectral envelope (Strong & Clark, 1967), ratio between overtones (Seashore, 1939) or formants (Plomp, 1976) within a complex sound. Though measurement equipment can be used to separate components of a complex tone into smaller pieces, we tend to combine these factors into a holistic impression of sound and hear it as a single 'sound'. With training and experience, we can discriminate between more specific yet different timbres of complex tones (Saldanha & Corso, 1964).

The concept of the Gestalt can also be used to explain how we read notation, as various symbols can be combined to form a single impression (staff lines, bar lines, note heads, stems, beams, etc.) or several impressions can also form a single idea (e.g. several notes creating a meaningful pattern of a certain chord or scale). To illustrate this point, Figure 1 shows an example of a recognizable melody written in standard notation. Once the melody emerges as familiar to the viewer, the way in which each tiny bit of information is examined is streamlined.

Figure 1- Yankee Doodle Melody in Standard Notation

In most cases, the example shown in Figure 2 is more challenging for the viewer to see a larger pattern emerge, and therefore the way in which each note, accidental, rhythm, etc. is examined will be different than in Figure 1.

Figure 2- Yankee Doodle Melody in Non-Standard Notation

After careful examination, it can be determined that both examples would sound identical, and depict the melody from "Yankee Doodle" in the same exact sounding key, however, it is likely that the example shown in Figure 2 would be a more involved task for the reader. It does not take advantage of several larger Gestalt ideas built in to standard music notation such as key signature and standard rhythmic beaming.

Figure 1 most likely allows a trained musician to recognize emergent patterns in a holistic manner. This naturally occurring phenomenon of smaller symbols combining and forming a Gestalt that naturally emerges accounts for both efficiency (less cognitive resource needed for perception as learned symbols become more complex) as well as effectiveness (perception can be more generalized with flexibility to add complexity only when needed (Wertheimer, 1944). In Gestalt psychology the whole is primary to the parts, not a result of, which shifts theory of mind in a direction that favors a type of cognition best explained not through analogies of processing (e.g. information processing models comparing brain activity to a computer processor i.e. bottom-up), but instead through emergence (top-down (Engel, 2001).

Classical Conditioning

Ivan Pavlov (1849-1936) was the first Russian scientist to win a Nobel Prize and is one of the most influential scientists of the modern era. He spent several years researching digestion with canines and it was because of this research that he discovered what would later become his most well-known contributions to mainstream science: the concept of *classical conditioning*. Pavlov would bring food to his canine subjects, and ring a bell whenever it was feeding time. Over the course of hundreds of trials, Pavlov would foster associations between the ringing of the bell and the presence of food. Then, Pavlov discovered that even with the absence of food, he could ring the bell and dogs would still exhibit the same responses as if the food were present (e.g. salivation, excited movement, etc.) (Plaud & Wolpe, 1997). Pavlov's concept of conditioning was simple and easily understood. The basic example of some kind of input followed by some kind of output was so easily demonstrated in a live context that the Russian government quickly adopted his scientific findings and supported his research. It was a modern example of Sir Isaac Newton's action-reaction law of motion.

Operant Conditioning

While classical conditioning dealt primarily with reactions (involuntary behavior), *operant conditioning* (also known as instrumental learning) was another behaviorist theory that described behavior as being shaped through a system of rewards and punishments (Jenkins, 1979). Edward Thorndike (1874-1949) was credited with being the first scientist to formally study operant conditioning as he developed his "Law of Effect" through extensive study of cat behavior in laboratory tests (Thorndike, 1927). Through several trials, cats were able to escape from a puzzle box with increasing speed, and his law described how behaviors that elicited successful outcomes were repeated more, thus feedback shaped behavior (Miltenberger, 2008).

The work of Pavlov et al in classical conditioning and Thorndike et al in operant conditioning paved the way for theories of cognition such as Stimulus-Response (S-R) psychology and information processing (Gibson, 1960), and to a large extent, how scientists and engineers approach computer programming (Sowa, 1983). It is reasonable to suggest these behaviorist theories could contribute to shaping brass pedagogy. Sounds produced by a brass player can elicit a number of different learned responses and create strong associations via a feedback loop that can be learned and refined over time. Concepts such as environmental constraint and goal-directed behavior are incorporated into theories derived from these streams of research.

The Unanswered Questions of Conditioning and Movement

Classical and operant conditioning addressed learning and movement from a behaviorist viewpoint, and several aspects of learning and movement were not taken into consideration, which created some limitations for the development of brass pedagogy. Based on the theories derived from both classical and operant conditioning, several questions emerge in regards to human movement itself. First, if learning is based on behavioral responses (movement) how do we store conditioned responses for every stimulus? Is there overlap and if so, how does it work? Second, if we have certain movements that are learned as responses, how far do we scale the control of movement? Do we control each individual muscle fiber or joint in the body to move the same way as before? There are millions of muscle fibers and hundreds of joints in the body. How much do we control each of these when we move? Third, how do we function in a novel situation? If there is no conditioned response already learned, how do we respond to new stimuli? Fourth, what if our bodies are not in the same posture to enact the learned response? For example, if we learn a response to a stimulus that involves extending our arms away from the sides of our bodies, what happens when our arms are situated over our head and the stimulus is presented? This would require different muscular use. Is that a new response that needs to be learned?

There are obvious questions of storage, scaling, novelty, and context that the behaviorist theories of classical and operant conditioning did not address as examinations in these fields primarily focused on behavioral output rather than internal mechanisms such as neuromuscular control of movement. Though S-R psychology and information processing contributed by adopting some of the principles driving behavior into cognitive study, they too fell short on answering these questions. Any concepts in brass pedagogy that do not take into consideration a more comprehensive synthesis of ideas ranging beyond behaviorist theories run the risk of either being too narrow in accurately representing the breadth of context that is assumed by brass players, or too specific as it is possible to produce a 'correct' response with a myriad of different methods of tone production. One needs to also examine psychomotor learning theories to more fully understand these difficult concepts of movement in relation to storage, scaling, novelty, and context.

The Lost Contributions of Bernstein

Near the same time of Pavlov, there was a Russian scientist named Nikolai Bernstein (1896-1966) who was trying to address the above concerns. Bernstein had an entirely different view of motor learning and motor control and tried to address it through psychomotor research (Bongaardt, 2000). Bernstein believed that movement was not 'controlled' at all. He developed experiments to challenge the problems of novelty, storage, and cognitive control of movement that were well ahead of his time. In one study he created a weighted ball that was suspended by a rod where the rod would extend out from a person's abdominal area. The ball was then controlled by two additional rubber bands held by a subject's hands. A subject would walk across the room with the goal of controlling the ball by controlling the bands, but with each step, the supporting beam would sway and move. This caused a constantly variable environment from which subjects had to steady the ball. Bernstein was able to show that even in this enormously complex environment of constant variability and novelty, subjects could control the ball while walking (Bernstein, 1967) (See Figure 3). His findings were substantial in that the scenario presented to test subjects was highly complex, highly variable, and highly novel, yet subjects were able to succeed without a great deal of cognitive awareness of movement (knowing which muscles needed to be used, etc.) and without several trials (subjects were demonstrating ‘mastery’ in a novel situation (Whiting, 1984).

Controlling movements of a heavy ball with two rubber bands. The lever is connected to the neck with a nonextendable cord to eliminate the effects of gravity.

Figure 3- Illustration of Nikolai Bernstein’s Movement Experiment- Walking with Weighted Ball (Bernstein, 1996)

His findings challenged traditional beliefs that were not clarified through behaviorist theories alone. There would be no way subjects would be successful if a learned response for each movement was required beforehand. Furthermore, Bernstein illustrated the complexity of movement by examining muscles and equating their movement to springs. When a muscle is extended (lengthened), it will behave differently than when it is contracted (shortened), thus suggesting that all movement is highly context-dependent. A slightly different context would require slightly different usage of muscles. How could a learned response be adapted for different contexts?

Last, the spring-like muscles were attached to limbs that acted like pendulums. Different joints of the body allow movement on different planes. For example, the fingers perform flexion and extension only on a single plane. They are constrained by their hinge-like joints. The arm, however, can move on multiple planes because of our ball-in-socket joint in the shoulder. Bernstein examined each joint and determined the number of degrees of freedom each joint provided. By explaining a simple movement of grabbing a cup, Bernstein demonstrated that there would be literally thousands of combinations of arm movements based on the degrees of freedom in the fingers, wrist, elbow, and shoulder joints. Bernstein suggested that each response for the same task might actually be different in terms of muscular use, and was instead context-dependent (Bongaardt, 2001). There would be no way to monitor that much information, even peripherally. Bernstein was trying to demonstrate that most movements are not monitored at all at an executive level (cognitively).

Bernstein exposed more questions than answers. His findings created theories of muscular movement that were messy. This was most likely a contributing factor as to why his findings were considered controversial, and with no governmental support, his ideas fell out of favor (giving way to Pavlov's theories, which were much more digestible by the Russian government). Unfortunately, Bernstein's work was largely forgotten. The progress that could have been made with movement theory had to wait until modern scientists could no longer avoid the challenges that Bernstein was trying to address seventy years before. Most of his writing was not translated into English until quite recently (mainly by Ines M. Rubin and Iosif Feigenberg, though some of Bernstein's work is still not translated (Feigenberg & Meijer, 1999) which is why most people are unfamiliar with his research. The problems that Bernstein was trying to solve remain relevant today.

Bernstein was revolutionary in that he was trying to answer difficult questions regarding how the body moves and refines movements from an empirical standpoint. His beliefs that movement was barely controlled at all has gained support with modern-day measurement (explained later in Chapter Two) and the significance of his theory that movement is highly context-dependent and controlled through goal-directed behavior cannot be understated for the field of brass pedagogy. To practice anything on a brass instrument too far away from authentic context or void of the same goal can become highly inefficient if not problematic. Examples where this applies specifically to pedagogy are included in Chapter Three.

20th Century Measurement of Movement

As a byproduct of the industrial and technological developments of the 20th century, research equipment has been constantly evolving to expose an ever-increasing amount of detail specifically within the human body. X-ray, ultrasound, and functional magnetic resonance imaging (fMRI) changed the way we study human anatomy and physiology empirically. In the early 20th-century, exercise was viewed as an increasingly important aspect of human life as multiple scientists started making landmark discoveries with researching specific functions of the human body. In 1920, August Krogh (1874-1949) won the Nobel Prize for his examination of capillary physiology (Krogh & Lindhard, 1920). Archibald Hill (1886-1977) and Otto Meyerhoff (1884-1951) won the Nobel Prize for their discovery of how lactate, when combined with oxygen, converts to carbohydrate (Bang, 1936). There was a major push for the legitimization of physical education in schools beyond the country's need for "war readiness," and the fields of exercise science, kinesiology, and biomechanics started to thrive in this environment.

In the latter half of the 20th century, functional magnetic resonance imaging (fMRI) became a popular method for measuring brain activity in humans by using a trace element that is injected into the blood stream and then measured in different regions of the brain during a limited type of activity. Though fMRI measurement came with significant limitations (See Appendix), correlations could be made with which regions of the brain were active during an action that was observed. Electroencephalography (EEG) is a type of measurement that involves placing tiny electrodes all over the scalp and measuring brain activity in the form of electrical signals. EEG is quite complementary to fMRI and favorable to timing experiments in that EEG is far more specific in terms of the elapsed time in between action and measurement of action, however, it too comes with limitations (also in Appendix A). EEG and fMRI have emerged as the two most significant and widely-used forms of scientific measurement for brain activity to date.

21st-Century Explosion

By the 21st-century, scientists and researchers have been a part of an explosion of ideas, theories, and beliefs. Several branches of psychology, biology, and philosophy are developing and overlapping with each other. There are far too many branches of study to list let alone describe even generally. Fields like cognitive neuroscience combine psychology and neuroscience to investigate the biological aspects of cognition through the use of highly advanced measurement equipment such as fMRI and EEG. Some fields turn to developing computational models and theoretical models in an attempt to 'reverse-engineer' how we think and move (such as cybernetics) or physical models to mimic learning and movement (robotics, artificial intelligence, etc. (Pickering, 2010). Synergetics is the study of self-organization of open systems far from equilibrium, a modern continuation to account for earlier limitations in classical thermodynamics (Haken, 1983). Philosophy-driven fields of study and scientific fields of study have pushed each other forward, and not surprisingly, major theories of how the brain and body work sometimes contradict each other.

Currently, a growing chasm exists between defining the role of information in how we think and move. Some fields put an emphasis on the information as being the key element in the process of cognition (such as information processing) while the other side of the spectrum places information as ancillary to movement and the environment itself (e.g. situated cognition, dynamic cognition, embodied cognition). Scientists such as James J. Gibson (1904-1979) argued that the environment provides affordances (Gibson, 1977). The way in which we move and interact through our specific environment is the basis for cognition (he openly disagreed with information processing). According to Gibson (Gibsonian Psychology), information is the byproduct, not the driving force in learning, cognition, and movement (Gibson, 2014).

Where are we now? Modern thought on Movement and Learning

In summary, regardless of which specific streams of research or philosophical ideas one supports, researchers from several different branches of science have converged on a few general points that are crucial for modern brass pedagogy. The following principles can be applied generally to teaching and performance:

No Two Movements are Alike

With hundreds of joints, thousands of degrees of freedom, and millions of muscle fibers, each movement is a combination of countless interactions within the human body (Bernstein, 1967). There are an infinite number of movements that the human body can produce, and interestingly it seems that movements are never replicated exactly. Measurement techniques such as EKG or EEG show variations or 'noise' in every attempt to measure muscular movements in human subjects. The only consistent finding is the existence of variation within and between these subjects (Collier & Ogden, 2004). In regards to behavioral observation, two sounds, either produced by the same or different players that appear to be identical have shown variation in measurement. Slight or sometimes gross differences in waveform spectra or Fourier analysis indicate differences in sound (therefore coupled with a difference in physical movement) even if it is imperceptible to the human ear or eye. The only time this appears to contradict findings is when measurement equipment (or observation) is not specific enough. It is simply a matter of scaling. No two movements are identical, therefore no two sounds are absolutely identical in terms of measurement.

Movement is Context-Dependent

Joint angle, body position, fatigue, etc. will have an effect on how our body moves. If these factors are different, our movement will be different. Shaking someone's hand is relatively easy. The position one's arm is in before the movement will affect specific interactions between muscles and joints in order to successfully shake hands. The way in which muscles and joints are activated will be an emergent result of the environmental situation the body is presented with. The constant will be the goal that is guiding our movements (goal-directed behavior). Musical context will have an effect on embouchure formation/mouthpiece setting for brass musicians as notes placed in a certain context of range will have a significant effect on how the body is manipulated to produce the desired sounds.

Movement is Largely Unconsciously Controlled

With such complexity and novelty in our movements, it makes sense that we do not control every aspect of every movement consciously. Though we can consciously control movements, we typically offload this process to unconscious systems so we may utilize our limited attentional resources for more immediate concerns. We do not have to think about muscle engagement, force production ratios, or joint angles when moving a limb (though we can choose to consciously move). These factors are coordinated to a level of automaticity over time and as we offload aspects of the task, we develop a fluency of movement that far surpasses the level of smoothness during conscious control of movement. This type of movement is referred to as *autonomous behavior*.

The Environment Acts as a Constraint to Guide Movement and Learning

Drawing from ecological psychology, situated cognition, dynamic cognition, etc. the role of the environment cannot be understated in learning and movement within human beings. First, one cannot remove an agent from its natural environment and gain an authentic understanding of how it moves, learns, or thinks. The environment plays a crucial role in shaping cognition for an agent. With most of our actions being controlled unconsciously, the constraints provided by environmental affordances give the human body and brain boundaries with which to navigate. Much of our movement comes 'for free,' meaning it requires no additional cognitive effort as long as we keep the environment intact. Second, one cannot separate the brain from the body to further understand either one. The brain and body work together to navigate through an environment. Third, human beings are both complex and adaptive. There is a constant level of evolution occurring, usually in the form of gaining efficiency as it relates to a specific environment that the agent finds itself in. Any attempt to measure any aspect of learning, cognition, or movement must be considered as a 'snapshot in time' as actions are constantly evolving.

For example, if a person were suddenly placed in an environment that had a height limitation of three feet (perhaps permanently living in a cave or tunnel), this would create significant changes to our bodies, our brains, and our society. People would slowly become expert crawlers. Our brains would physically change over time and the neurological connections associated with coordinating bipedalism would disappear. Our neural mapping would shift due to usage. After several generations, mutations favorable to the new environment (such as greater deposits of calcium in the knee, thus thicker bones to support greater loads in the crawling position) would outlast previous genetic advantages of standing upright (perhaps longer femurs) and we would slowly evolve into an organism that was better suited for a lower-profile lifestyle. From an ergonomic standpoint, we would make advancements on equipment, furniture, etc. that fit our newly acquired lifestyle. We would adapt. There are countless examples of environmental constraint that span physical, chemical, cognitive, social, economic, and political landscapes. Some are barely noticeable to us, but constraint is the driving force behind evolution and adaptation. Musicians have examples of environmental constraint specific to their vocation. Without making an exhaustive list, the two most significant constraints musicians must work within are harmonic context and time. Both of these constraints (including suggestions to create methods that work within these constraints) will be examined specifically in Chapter Three.

Implications for Brass Pedagogy

Some impressive streams of research have developed over the last few decades involving topics highly related to brass pedagogy. The data found within these particular areas of interest have considerable implications for current brass pedagogy. In many cases, the current data suggests methods that are contradictory to common practice methods.

Time. Time plays a role as a major environmental constraint with any form of metered music. There are two main ways in which timing is an important factor to consider when developing 21st-century pedagogy.

Slower tempi in practice. The alteration of tempo for practice purposes has become a standard method of developing proficiency with both technical exercises and repertoire among all levels of musician. It is a common practice to slow down the tempo of a difficult passage and slowly speed up the tempo after successful repetitions are generated in the slower context. Research from the past century strongly supports the idea of a speed/accuracy trade-off (Fitts & Poser, 1967), which follows this conventional logic: when a performer plays faster, accuracy is sacrificed. Based on this logic, it seems to make sense to slow down difficult passages for more effective practice.

Research in biomechanics as well as kinematics suggests that as movements become more learned, more efficient usage of muscles and joints is observed. Movements become smoother and more streamlined. With automaticity comes fluidity. Similar findings have emerged through fMRI research over the past few decades (Kübler, 2006). With the innovation of fMRI, scientists have been studying images of brain activation as observed during cognitive action and (quite limited) physical movement in an attempt to explain correlations between brain activation and perception/action. A strong example of this research was conducted by F. Gregory Ashby and colleagues (Ashby, 2007), who have examined pigeons performing the same actions over time through several hundred trials as a way to view reorganization of brain activity as an action becomes mastered. Their findings suggest that actions can correlate with activation in certain regions of the brain, but over time and repetition, these active regions change, suggesting that as tasks are automated, neurological connections are shifted so far as to include or avoid entire regions of the brain. As a movement becomes learned to the point of mastery, a slow shift of physical activation morphs towards smoother, more economical movements that require both less cognitive demand and physical energy (d'Avella, Saltiel, & Bizzi, 2003).

From a neurological standpoint, this emergent field of scientific observation called neurodynamics is starting to focus on observing the same pruning of superfluous effort as neural activity evolves to exclude cognitive areas of the brain which can become cumbersome when time is present as an environmental constraint. Ashby's team worked with pigeons (since they lack a pre-frontal cortex), and their theory was that as tasks are learned toward a high level of autonomy, the more cognitive areas of the brain are pruned from the process (Ashby, Ennis, & Spiering, 2007). They were able to demonstrate that pigeons reached this level of mastery faster since there was no need for a major shift neurologically from cognitive regions to more unconscious regions (as pigeons lack the neural anatomy of cognitive regions comparable to humans).

The current data suggests that more accuracy can be attained at slower tempi (Fitts, 1954), and also that movements at faster tempos engage different parts of the brain, different ratios of muscular movement, etc. which implies that musical performance that is taken too far out of the context of time is actually a different action altogether. This creates a problem for practicing musicians. If we generate dozens of repetitions at slower tempos, we might be developing stronger neurological pathways in regions of the brain that are too cumbersome to successfully manage performance at faster tempos. When the brain/body needs to prune off these superfluous connections, we might have made the goal of performance at original tempo more difficult by engraining these slower pathways initially. The slower versions of the same piece can potentially cause contextual interference where an action output needs to be selected from multiple choices subconsciously. For brass players in particular, breathing is also affected, which can lead to more opportunities for embouchure or mouthpiece shifts at different places than are found at faster tempi, etc. This will ultimately delay the focus on specific challenges that emerge only at the goal tempo.

External Source of Tempo. A second factor when considering timing as an environmental constraint is the use of an external source of tempo. This is most commonly done with the use of a metronome. From a research perspective, timing has been most commonly studied in a format where first an external source of tempo is presented to a subject and the task is to coordinate movement (usually tapping) to line up with the pulse of the metronome. This task is known as a sensorimotor synchronization task or SMS (Bartlett & Bartlett, 1959). At some point in the experiment, the external source of tempo is removed and the subject must continue to tap the same tempo, with equipment measuring the performance of the subject relative to the original tempo. This is known as a continuation task.

SMS/continuation experiments are the most common type of timing experiment and have been conducted for well over a century (e.g. Dunlap, 1910; Stevens, 1886; Woodrow, 1932). One common finding to all timing experiments is that human subjects are not capable of perfectly continuing with a steady beat. There seems to be no such thing as 'perfect time' exhibited by anyone, even trained musicians. Variations, 'jitter', and drift from original tempo is found during continuation tasks (Collier &

Ogden, 2004). The amount of variation is diverse among test subjects, but trained musicians show less variation (Drake & Botte, 1993; Peretz & Zatorre, 2005). One might argue that musicians had an innate ability in regards to timing, which helped them self-select music as a career path, however non-musicians have shown improvement in tapping ability in SMS/continuation tasks after some training (Kristofferson, 1980) which suggests that timing can improve with practice and it is likely that musicians have just practiced more on timing.

We know musicians have practiced keeping good time and a popular method of practice involves some type of metronome. The next logical conclusion would be that metronomes help develop timing. Interestingly, advancements from recent research suggests the story is not so simple. Since the wide-spread use of advanced measurement equipment such as fMRI and EEG, data clearly suggests that SMS uses different regions of the brain than continuation (Gerloff, Richard, Hadley et al, 1998; Lewis, Wing, Pope et al, 2004).

Continuation seems to be a more demanding cognitive task than SMS (Jantzen, Steinberg & Kelso, 2004). This research implies that practicing with a metronome is actually a different task. The metronome acts as a crutch by providing different constraints. Worse, using a metronome is engaging the brain differently, which then makes the task of keeping time independently more difficult to master. Specific suggestions for how to best practice within the constraint of time is discussed in Chapter Three.

Harmonic context as environmental constraint. Music in the Western tonal tradition is usually written with an underlying basic chord structure that can be reduced to a simple pattern of starting with stability, following it with instability and resolving back to stability (tonic, pre-dominant harmonies, dominant harmonies, and resolution back to tonic (Benward & Saker, 2009). At its most basic fundamental level, a homeostasis is established through the use of triads that outline a key or tonal center. Once an expectation has been established, the music then deviates away from this tonal center which creates tension and expectation for the listener. Though composers have employed different methods to deviate away from, and return to an established harmonic position, it is reasonably agreed that the general term of "Western tonal music" refers to a style of composition that creates this form of tension and resolution using the same fundamental principles as Pythagorean tuning.

In the 6th century B.C., Pythagoras (570 B.C.-495 B.C.) described the relationship of frequencies using whole-number ratios. An octave was described as a 2:1 ratio of vibration (e.g. twice the frequency sounds one octave higher), the Perfect 5th as a 3:2 ratio of vibration, the Perfect 4th as a 4:3 ratio of vibration, etc. The pattern was continued to create intervals as small as a minor 2nds (8:7 ratio) and these intervals were used to create diatonic scales made up of half steps and whole steps (Crocker, 1963). Different tonalities such as major, minor, augmented, and diminished can be created using different patterns of these intervals, however, the octave served as a pillar at the most basic of hierarchical levels. At the next level, octaves were commonly split into a perfect 4th and 5th, which created a chord structure that composers used as a harmonic constraint. Since the octave was not split equally (the tritone was historically avoided and even now is considered quite dissonant by comparison to the Perfect 4th and 5th) (Smith, 1979) and the uneven distribution of intervals (five half steps versus five to make up a perfect 5th and 4th respectively) created momentum through gravitation towards a smaller interval of resolution. Because of this, a chord progression involving Octaves, 4ths, and 5ths is usually not perceived as stagnant. It has motion and energy. It is the energy created by this dynamic harmonic progression that has served as the canvas of Western tonal music (Rohrmeier, 2011).

The energy created by the asymmetrical harmonic progressions found in Western Tonal music mimics the same gravitational energy that is found within other scientific disciplines. Einstein's general theory of relativity describes gravity as being caused by a curvature of space-time and thus an elliptical (not circular) pathway (Hawking, 1979). There is an unevenness to positioning, which creates context-dependent momentum and gravitational pull. Imagine a bicycle with an elliptical wheel. There would be a point within each revolution where momentum increased and the bicycle was propelled forward more rapidly. It is the same unevenness that can be used to describe Kepler's Laws of planetary motion (Aiton, 1969). The distance between tonic and dominant (or sub-dominant and tonic) together form a dynamic system that is constantly propelling towards resolution using the same type of uneven distribution found abundantly throughout the physical universe.

Western tonal music has developed over the centuries, but the basic patterns and expectations that are embedded within the typical chord structure and voice leading act as an environmental constraint for a musician. Musicians are well-served to develop effortless mastery in being able to navigate within this constraint. It would seem reasonable that exercises used to develop ease of playing and control of the instrument would be written with the same environmental constraints in mind, however, many exercises commonly used by musicians are not situated within the same harmonic context. Specific examples of exercises that do not follow a dynamic harmonic progression as well as suggested exercises that can replace these exercises are introduced in part two.

Contemporary harmonic context. An additional aspect of 21st-century pedagogy is the development of harmonic context that goes beyond the classical tradition of Western tonal music. In the 20th-century, Western music went beyond classical tonal harmonies mentioned above. Composers like Wagner and Webern were taking advantage of huge chromaticism (Jones, 1976). Claude Debussy (1862-1918) was using bipolar tonalities built with Major seconds (e.g. two whole-tone scales that do not share a single common note) (Albersheim, 1960). Diminished and augmented harmonies were constructed using even intervals of minor and major thirds respectively. Hindemith and Scriabin were utilizing the sounds of stacked 4ths (Morrison, 1998) while Copland was employing similar techniques by using 5ths (Kleppinger, 1999). Any musician wishing to truly develop the ability to navigate within current harmonic frameworks must not only develop mastery of harmonic context in a classical sense, but also must be thoroughly autonomous in playing within a context of single stacked intervals. Specific exercises that focus on these intervals are introduced in Chapter Three.

A blocking effect for reading music. From a harmonic standpoint, Western tonal music is written by using twenty-one different key collections that create a total of twelve different sounding keys. Music notation is commonly written with a key signature, where a collection of notes is assumed as a default unless otherwise notated. Key signatures are placed at the beginning of a line or section of music and the performer then interprets the following section with the key signature as a guideline (Kostka & Payne, 1995). When music modulates to a new key, a new key signature is presented. In many cases, the new key signature presents complications in that the same visual symbol from before now has a different meaning, and therefore a different response. The challenges that this system of notation presents require music teachers to take into consideration visual dissonance, blocking effects, and contextual interference when determining the most effective ways to teach music reading literacy.

Visual dissonance refers to a conflict between what one sees and what one thinks. Examples include seeing two different symbols that evoke the same meaning or seeing one symbol that has two or more different meanings (Solso, 1933). This is most evident in music notation as two different sounding notes will look the same visually in the staff, because the only difference between the notes is through the use of the key signature, which looks identical to the visual symbol in question. Conversely, two different symbols can sound the same and be performed the same on an instrument, such as enharmonically equivalent notes. Research in several different areas including animal behavior and linguistics has examined blocking effects for associating stimuli with responses. Leon Kamin (1968) first introduced the concept of a blocking effect in the late 1960's in experiments with rats similar to Pavlov's (see above). By presenting food with a stimulus (such as ringing a bell), rats created a conditioned response to the presence of the bell without the presence of food. After this conditioned response was present, a second stimulus was added to the presentation (such as shining a light). Rats were unable to associate the light with the food independently, because the stimulus of the bell had blocked the association between the sound and the food. Interestingly, research has also been conducted to determine how long it would take to reverse blocking effects. Blaisdell, Gunther, and Miller (1999) experimented with rats and determined that in some cases the ratio of reversing a blocking effect took trials of roughly 50-to-1 against the originally conditioned response.

Research from kinesiology and motor learning shows similar findings in the area of contextual interference. Interference is described as multiple (and sometimes conflicting) types of stimuli used to create associated responses. To draw from an earlier example, both the bell and the sound could be considered as examples of contextual interference. Battig's general conceptualization of memory is built around the idea that increased contextual interference during learning trials leads to increased retention and transfer (Battig, 1979). Shea and Morgan demonstrated this by using a task involving knocking down cups as a reaction to a specific sequence of stimuli. When the stimuli was presented in a blocked format (all trials of one response presented first, all trials of a second response presented second, etc.), performance appeared to be favorable during the learning phase over random groups (groups of test subjects that were presented with all possible stimulus-response scenarios at once in a random order). In a retention tests, both after 10 minutes and two weeks, the random group performed significantly faster with less errors, suggesting that the blocked trials created a similar blocking effect (Shea & Morgan, 1979). This concept of a blocking effect/contextual interference can be seen throughout our most common teaching methods for brass instrumentalists. Specific examples of exercises that account for visual dissonance, blocking effects, and contextual interference as well as suggested exercises that can replace these exercises are introduced in Chapter Three.

Embouchure. Embouchure refers to the formation of muscles in the face to produce sounds on brass instruments. Embouchure has become a dangerous word for brass teachers and students as its meaning has developed into a more rigid commandment with no room for individualization, variability, or context. At the conclusion of the 'brief history of perception and action' above, four major points emerged as principles that act as a summary of perception/action. The following same four points are imperative when considering 21st-century brass pedagogy as it relates specifically to embouchure:

1. No two movements are alike
2. Movement is context-dependent
3. Movement is largely unconsciously controlled
4. The environment acts as a constraint to guide movement and learning

By applying those factors directly to embouchure, major conflicts emerge between theory and common practice.

No two movements are alike, therefore no two embouchures are alike. In *A Photographic Study of 40 Virtuoso Horn Players' Embouchures*, by Philip Farkas (1914-1992), visual differences in the embouchures of forty professional players is clearly evident and in some cases egregious (Farkas, 1970), but this is just the ‘tip of the iceberg’ in terms of human anatomy. Some teachers (specifically ones that become known as embouchure specialists) teach embouchure with a “one size fits all” mentality, however as mentioned earlier, in the history of recorded science, no two people have been found to be identical in terms of anatomical measurement. There is no evidence to support the idea of a standardized or consistent embouchure. One of the most comprehensively documented studies of embouchure was published by Donald Reinhardt (1908-1986), who classified embouchures using four generalized categories along with eight different ways to use the tongue while articulating (Reinhardt, 1942). The generalized categories that Reinhardt created resemble the intentions of Richard Schmidt’s description of human movement through a ‘generalized motor program’ (Schmidt, 1972a), which describes generalized movements learned and adapted for specific use. Schmidt’s work was never intended as a means to classify movements for individuals with rigid specificity, and the scientific community never interpreted his work as an over-explanation of motor control. Reinhardt’s contributions to embouchure could best be described as an attempt to show similarities between embouchures as a broad, general idea and not a classification system from which to diagnose specific adjustments and corrections to embouchure itself.

More importantly, however, within a single player, no two performances of the same note will yield the exact same setting of the mouthpiece against the lips as lips, like every other part of the human anatomy, changes in shape constantly due to muscle fatigue, hydration, sun exposure, etc. Each note that a brass player plays will show nuance differences in both visual/graphic presentation (waveform analysis) as well as muscular readings (EEG, etc.). It is important to remember that even Reinhardt based his research entirely on his own observations of both his own playing and the playing of his students. There was no measurement of muscular activity and no control for variations in playing examples from a single player. The important matter of scaling comes to the fore when dealing with embouchure as it does with movement. Though slight differences might not be visual or audible, the fact that they still exist has implications on how we should approach embouchure pedagogically. There is no regard for scaling of scientific measurement within the published literature of embouchure. A vast majority of findings are documented only through observations, interviews, and speculations made by musicians regarding human anatomy.

Movement is context-dependent, therefore embouchure is context-dependent. Any note played on a brass instrument is done so with some kind of embouchure, but everything that has happened before and leads up to that note will affect one's embouchure or mouthpiece setting. Different levels of fatigue or hydration, the previous notes within a phrase, etc. will change the starting point from which the facial muscles need to move to create what is the most optimal way to play a particular note. This will depend on the context to which the note exists. The embouchure or setting that a brass player plays a B^b4 as the highest note in a phrase will be different than the embouchure or setting used to play a B^b4 that is the lowest note in a phrase. Though many brass musicians approach playing with a consistent 'feel' to setting a mouthpiece and returning to the same setting, no scientific evidence exists to suggest that the formation and use of an embouchure is any different from the way any other muscles in the human body function. Therefore it is reasonable to estimate that the muscles will respond uniquely under changing circumstances.

Movement is largely unconsciously controlled, therefore embouchure is largely unconsciously controlled. Immense complexity exists with the muscles that form and manipulate a brass embouchure. The orbicularis oris muscles alone contain numerous muscle fibers that are situated circularly around the mouth. Only recently was the classification of the orbicularis oris changed from a sphincter muscle to a collection of four overlapped muscles (Saladin, 2009). Most of the control of these fibers, as well as the rest of the muscles that make up an embouchure, is done unconsciously. It is true one can temporarily control aspects of facial movement consciously, however, this task is usually offloaded as soon as more engaging tasks (such as playing an instrument) are taken up. Furthermore, the human body is not designed to sense or control individual muscle fibers. With movement being largely unconsciously controlled, there is no scientific reason to suggest anything different for the specific use of a brass player's embouchure.

The environment acts as a constraint to guide movement and learning, therefore the environment acts as a constraint to guide use of embouchure. The most common examples of teachers or students actively manipulating and changing an embouchure happen outside the context of an authentic playing environment. The music itself provides constraint that requires adaptation. If a performer only needed to play a B^b4 and this was required hundreds of times a day, then that performer's embouchure and setting would slowly morph into the most optimal setting for the B^b4. After weeks or months, the embouchure would be considerably different than one that can accommodate the entire working range of an instrument. Mouthpiece placement can also act as a constraint. Though general considerations can be made in terms of mouthpiece placement, there is no set way for everyone to follow. Jean Baptiste Arban (1825-1889) vehemently opposed the 'orthopedic system' (moving the mouthpiece to a more favorable location on the face) that was present in the pedagogy of the French Conservatory during his tenure, going so far as to write "no absolute rule for the position of the mouthpiece exists" (Arban, 1936, p.6). Often teachers and students rely solely on confirmation bias when attempting to adjust their own embouchure or that of a student which inaccurately justifies the effectiveness of the method of instruction. When a student changes his/her embouchure and finds limited progress, no progress, or a regression of abilities, teachers tend to blame the student with anything from a lack of properly administering the technique to a lack of motivation/practice or even a lack of talent. When a student is successful, teachers tend to add this confirmation to their reasons why their method is successful for a much broader population.

In order to accurately understand embouchure, we must examine movement both in anatomy as well as kinesiology. By familiarizing ourselves with basic principles of anatomy, physiology, and motor learning/motor control, we can develop more effective ways to address embouchure with our students and avoid antiquated methods that have plagued our pedagogy with ignorance for so many years. Specific suggestions for the development of embouchure are made in Chapter Three.

Chapter Three: 21st-Century Techniques

Using parts one and two as a starting point, several important factors emerge in regards to movement, learning, and cognition that have direct impact on current brass pedagogy. These factors can be used as a foundation to build a 21st-century version of brass pedagogy that will provide more efficient and productive methods of practice and can serve a wider range of players and teachers alike. Taking each of the major topics from part one (time, harmony, embouchure), here are some typical examples of how brass players address these factors within practice as well as some suggested examples that align more closely with current research implications.

Time

With time as an environmental constraint, repertoire and specific exercises are less of a concern than the way they are approached. As mentioned earlier, practicing with a metronome can provide insight as to a player's consistency with tempo, however it does not help develop an independent an autonomous ability to maintain good time. Practice without a metronome provides no reference of comparison. The best option for developing a good sense of time and timing in brass performance is to use an external source of stimulus that provides some temporal information, but also intentionally leaves some out.

Metronome apps with randomization. A metronome or metronome app that randomly removes beats is the most effective way to bridge the gap between SMS and continuation training. While not going too deeply into available sources as this list will change greatly even during the writing of this document, *TimeGuru* and *Metronomics* are good examples of apps that currently include this technology. Some might prefer audio tracks of metronome tempos with beats randomly removed such as *Innovative Practice Tools- Random Metronome*. These mp3 files can be downloaded to any media device. Other 'low tech' options include programming a Dr. Beat to loop through silent beats (both the DB-88 and the DB-90 have this feature). The audible beats and silent beats can follow a loop, but loops can be created that are difficult to entrain to, especially with the DB-90 and its 50-capacity program tempi. Lastly, practicing with a partner where the partner randomly turns down the volume of a metronome can work just as well. All of the options mentioned here cost less than $10 and provide a greater level of effectiveness with helping a brass performer to develop an independent sense of time. It would be in the best interest of any brass player interested in improving their ability to play with more consistent timing to utilize any of these forms of technology into their practice regime.

Keeping time as an intact environmental constraint. Slowing down the metronome can cause just as much harm as help if done too soon or too often within the learning process. Neurological pathways need to be formed in the context of time to insure they will work when music is scaled back up to goal tempo. Rather than starting slow and working up to speed, the following methods might be more beneficial for developing long-term success with technical passages that require advanced speed and technique.

Chaining: A 21st- century alternative to slow practice. Chaining is a term used to describe putting together smaller pieces of a sequence in an attempt to learn a more complicated pattern of events. Skinner and Ferster (1957) were the first to attribute the phrase to a method of learning. Their procedures included examples of teaching a bed-time routine to a child where brushing teeth, changing clothes, etc. could all be learned and chained together to create a learned sequence of events that a child may execute daily. Each individual task could be broken down further (for example grabbing the toothbrush, applying toothpaste, turning on the water, etc.) and as the task becomes learned, it could be chained to other tasks. Their methods of instruction could facilitate learning a complex order of actions that would be more difficult to learn as a whole. Though their work was significant in the field of behavioral psychology, it is important to note that music performance requires a stricter adherence to the constraint of time, which was never explicitly prioritized in the work of Skinner and Ferster. Chunking is another term often used to describe the concept of combining single bits of information to increase the productivity of a human's limited capacity of short term/working memory. George Miller's research (1956) involved using this method during free recall (recalling presented terms in any order) and serial recall (recalling terms in the order they are presented) tasks to test memory, however these memory tasks also did not need to prioritize timing to learn complex coordinated tasks. Neither chaining nor chunking include the element of time as an important constraint, however, the term chunking will be used here to describe the methods of linking together parts of a sequence for practice purposes as it most closely resembles the type of procedure recommended for musicians.

Types of chaining. The following example will be used to describe some of the different ways that chaining can be used. Figure 4 shows a line of music that would be rather difficult to play at a moderate tempo. The labels “m” for Measure and “b” for Beat will remain consistent through all subsequent Figures.

Figure 4- Complete Excerpt Used for Chaining

Microchaining and Macrochaining. Microchaining refers to taking a passage and breaking it down to its smallest parts, in this case, 16th notes. As multiple 16th notes are chained together successfully, larger groups can be used for macrochaining. A reasonable example of macrochaining might involve taking each beat of four sixteenth notes and combining beats of four 16th notes together. A helpful analogy might be to think of a sentence and equate microchaining to combining letters together and macrochaining to adding words together in order to develop fluidity in performing the sentence.

Forward, Backward, and Goal Chaining. Forward chaining refers to starting at the beginning of a passage and adding units that follow. Backward chaining is the reverse where the final unit is the starting point, and the performer adds previous units in the sequence in an attempt to from an earlier starting point. Goal chaining is when the performer starts at a difficult place within the passage and alternates adding units before and after it to chain it together. Using these terms, here are several different ways to practice the original complete excerpt:

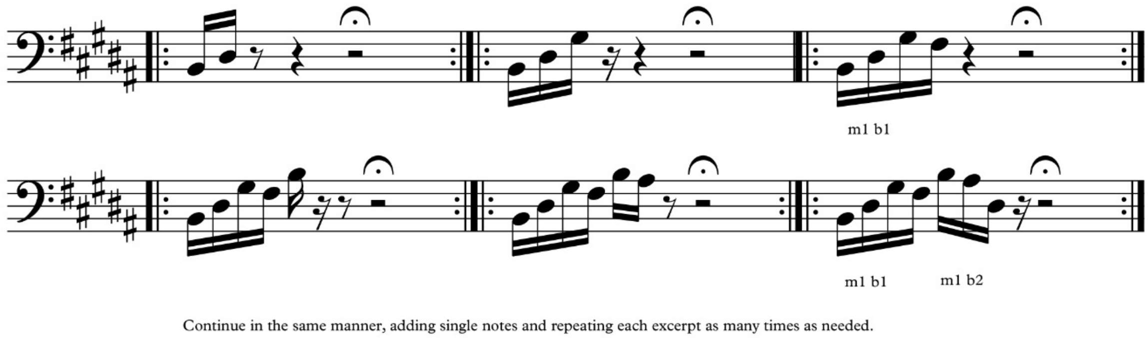

Figure 5- Forward Microchaining

In forward microchaining (shown in Figure 5), the performer would start by playing the first two notes in the same relative tempo as the passage calls for. As the performer masters the first two notes, he/she would add a third note and repeat the process. The performer keeps adding notes as the new passage becomes mastered.

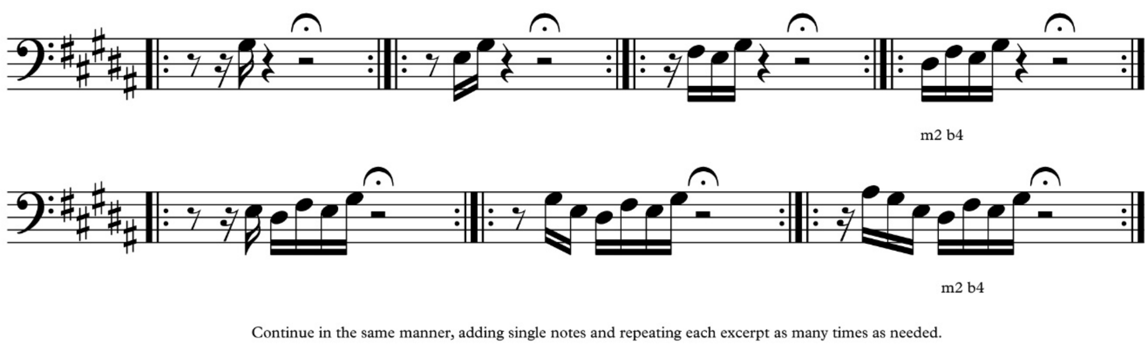

Figure 6. Backward Microchaining

Backward microchaining (Figure 6) is similar to forward microchaining but instead of starting at the beginning and adding notes that occur after, the performer would start at the end of a passage and add previous notes as proficiency was gained.

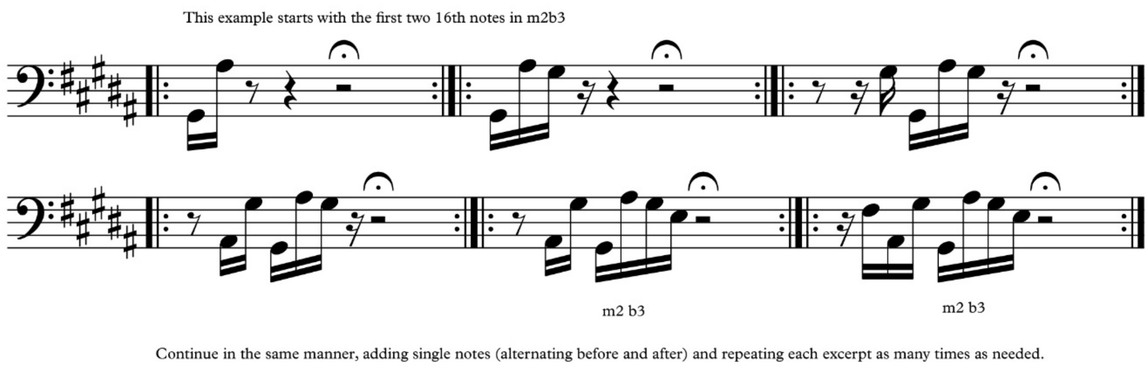

Figure 7. Goal Microchaining

Goal microchaining (Figure 7) differs from forward and backward microchaining in that the performer starts with a specific place within the middle of an excerpt (rather than an arbitrary place, beginning with the most difficult section of the passage might be more productive). The performer then slowly adds notes before and after in an alternating manner to keep the beginning notes within the middle of the section being addressed.

As described earlier, the same system of practice can be applied to a marco-level. Below is an example of Forward macrochaining (Figure 8), where each beat is treated as a discrete unit, and beats are added as the performer becomes more proficient. It is important to note the additional 16th note which provides the connection to the following beat. This note will overlap between examples creating a stronger connection between units.

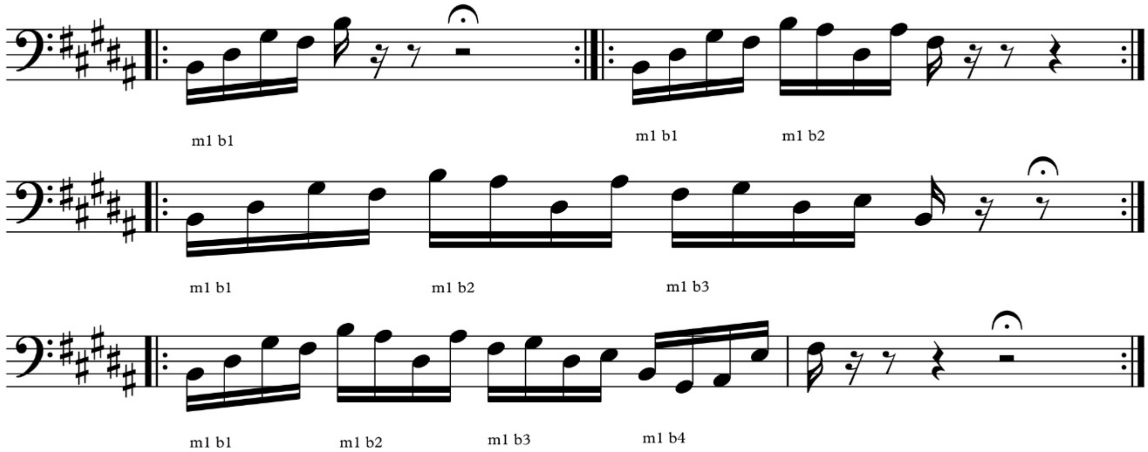

Figure 8. Forward Macrochaining

Below is an example of Backward macrochaining (Figure 9) and similar to the ‘micro’ versions, the performer starts with the final unit and adds previous units as proficiency is gained.

Figure 9. Backward Macrochaining

Goal macrochaining (Figure 10) provides a similar focus on a troublesome place within the example by starting with a complicated unit and as proficiency is gained, the performer will alternate adding a unit before and a unit after. Since the excerpt starts in the middle of the example, one additional note is added until the end of the excerpt is reached.

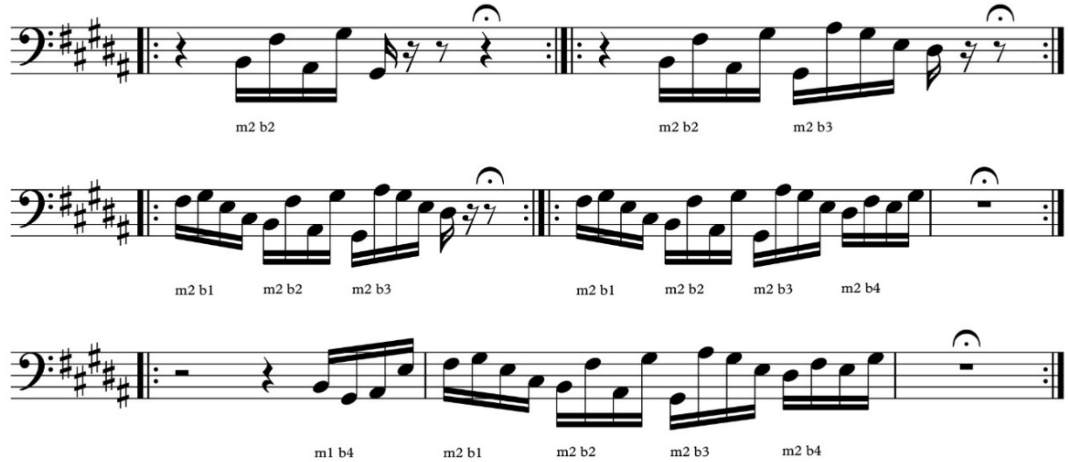

Figure 10. Goal Macrochaining

In-Phase and Anti-Phase Macrochaining. All of the examples of macrochaining presented thus far have used units that line up with beats within the music (four 16th notes that all exist within the same quarter-note beat). By referring to these examples as "in-phase", we can then delineate an anti-phase group of examples where the units exist over different beats. The following is an example of Anti-phase forwards macrochaining (Figure 11). Working in anti-phase provides a productive alternative that is complimentary to in-phase chaining methods.

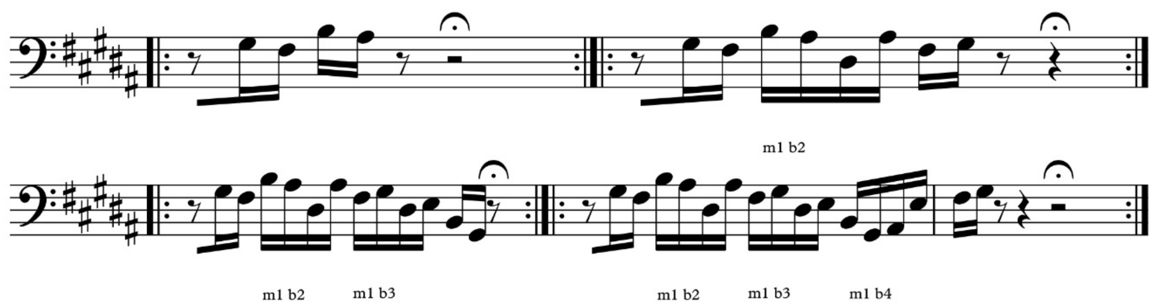

Figure 11. Anti-Phase Forward Macrochaining

Fractional chaining. Fractional chaining (shown in Figure 12) differs from all other forms of chaining in that the entire excerpt is presented with only a fraction of notes being played. Slowly the fraction is increased until the excerpt is played in its entirety.

Figure 12. Fractional Chaining

Proportional chaining (seen in Figure 13) is the only version that starts with all notes being performed but adds time in between macro-units to give the performer a chance to 'regroup' before the next unit is to be played. In this example, units are four 16th notes plus the following downbeat (a total of five notes) and are played in order with an additional three beats (including the overlapped downbeat) in between. Once the performer has this version mastered, the performer then cuts the rests down to two beats in between each example. Next, only one beat is present in between each unit. Following this, two units are combined (eight 16th notes plus a downbeat) with three beats of rest in between each new unit. This process continues until there is no additional time added to the excerpt. Proportional chaining still keeps the relative timing between 16th notes consistent, but operates like a macrochaining approach in that each unit is spaced out at first. The difference is rather than mastering the first unit and then proceeding to the next, all units are played so the performer can start to develop an overall consistency with playing the excerpt from the beginning to the end.

Figure 13. Proportional Chaining

This is not an exhaustive list of methods to practice repertoire while keeping the constraint of time intact. It is up to the performer to apply creativity to determine not only new approaches, but which approach(s) will most efficiently help the performer achieve the desired results.

Harmonic Context- The Use of Long Tones

It is impossible to discuss brass playing without discussing long tones as a major and crucial component to the development of one's playing. Long tones are an integral part of nearly every brass player's technique. Sustained sounds require control, clarity, and ease, and this can only be mastered through the practice of sustained tones.

Similarly, it is impossible to discuss long tones in brass playing without crediting Emory Remington (1891-1971) as one of the most influential contributors to the most widely-used versions of long tones throughout the brass world. Though most likely not the inventor of long tones, his "Remington Long Tones" exercises have become some of the most ubiquitous long tones exercises in the pedagogical repertory.

Emory Remington was first taught by his father (himself a cornet and trumpet player) and started playing the trombone ca. 1906 with performance records indicating a significant development achieved by 1909 (Remington, 2016). It is not surprising that his earliest musical experiences as a choir boy in an Episcopal church would continue to shape his noteworthy "singing" pedagogical style.

Remington's approach differed from other major pedagogues of the time, most notably that of Arban and Schlossburg with a singing-style approach. Without getting too broad or stereotypical, it is reasonable to believe that Remington's singing method, (most remembered by his long-tone warm-up) provided a necessary balance to the articulated style from the French and Russian schools of pedagogy mentioned above. Presently, players and teachers debate about the appropriate balance of lyrical and technical training, but both aspects of playing are adopted as standard requirements of comprehensive technique. Most music schools as well as summer festivals call for contrasting works between technical and lyrical styles. Orchestral auditions have repertoire lists that include excerpts of both technical and lyrical styles of brass playing.

An example of the Remington Long Tones Exercise would start from an open-sounding fundamental pitch and alternate between ascending/descending chromatically, and returning to that open-sounding pitch. An example is provided here (Figure 14):

Figure 14. Remington-Style Long Tones

Hundreds of brass players and teachers include some form or derivative of this exercise in their own personal approach or method. Many fine players credit their work with the Remington long tones as essential to their success, however, modern scientific theories might suggest that altering this approach could offer a more efficient and productive way of achieving the same success.

Limitations of Remington. The Remington Long Tones is based on the mechanical constraint of the open-sounding overtone series of a brass instrument. A player plays an open note (found in the overtone series using the shortest amount of tubing) and starts playing a pattern of increasing intervals from that starting point (minor 2nd, Major 2nd, minor 3rd, Major 3rd, Perfect 4th, etc.). The Remington Long Tones is used by Western musicians to develop their abilities to playing within a musical environment that have a specific underlying structure and yet this structure is absent from the exercise itself. It is true that the same intervals present in the Remington Long Tones are the same intervals found throughout Western tonal music, however, there is no larger underlying harmonic structure found within the pattern. Ironically the Remington Long Tones exercise has become associated with a "singing style" when most vocal warm-ups utilize set of constraints akin to Western harmonies. Most choirs and vocalists warm up using basic chord progressions or scalar melodies, and then modulate these basic chord progressions up or down, based on the desired range for the warm-up. From a harmonic standpoint, the Remington long tones are stagnant. There is no gravitational pull similar to authentic music of Western tonality.

Two main problems arise when this mechanical form of constraint (Remington) is used in place of an existing harmonic constraint (e.g. chord progressions). First, using the Remington Long Tones exercise will be less effective at helping to develop ease and control in sustained tones that function within Western tonal harmony. Phrase and cadence are removed and players instead have to fabricate a less authentic form of musical direction to the lines. It would seem to be more effective to instead use a system that keeps the same framework of tonality intact as the repertoire one is trying to master.

Second, by creating a long tones exercise that follows an easier, more repetitive pattern than a dynamic harmonic progression, players often become accustomed to the pattern too quickly and therefore lose awareness of what notes they are playing far too early in the learning process. Though this might seem contradictory to earlier concepts of offloading cognitive demand, it can become harmful if cognitive involvement is pruned off before players even develop a reasonable understanding of the notes of the instrument. The benefit of offloading cognitive demand is to enhance one's ability to focus on making a phrase, which is impossible if a concept of phrase does not exist in the first place. When the Remington long tones pattern is used in large band class settings, for example, far too many players have no idea what note they are playing, where the direction of the line is, where the natural phrase is leading, etc. and they develop a habit of playing that is less engaged, less informed, and less musical. This style of playing can stay with someone for years. The longer it is reinforced, the more challenging it will be to change when a player moves on to more advanced settings (such as university study). Rather than a smooth linear transition of improvement, this can create a barrier to higher-level playing for novice players.

A 21st-Century Alternative to the Remington Long Tones. As mentioned earlier, a form of long tones that follow a chord progression grounded in the same harmonic framework as Western music would seem to be a better fit for developing not only the same pedagogical attributes as Remington long tones (endurance, clear tone, etc.) but also a greater understanding of phrase, cadence, harmony, voice leading, etc. that is needed when performing the authentic repertoire of Western Music.

Here is an example of long tones that utilize the tonic (I) and dominant (V) chords as a harmonic framework (Figure 15):

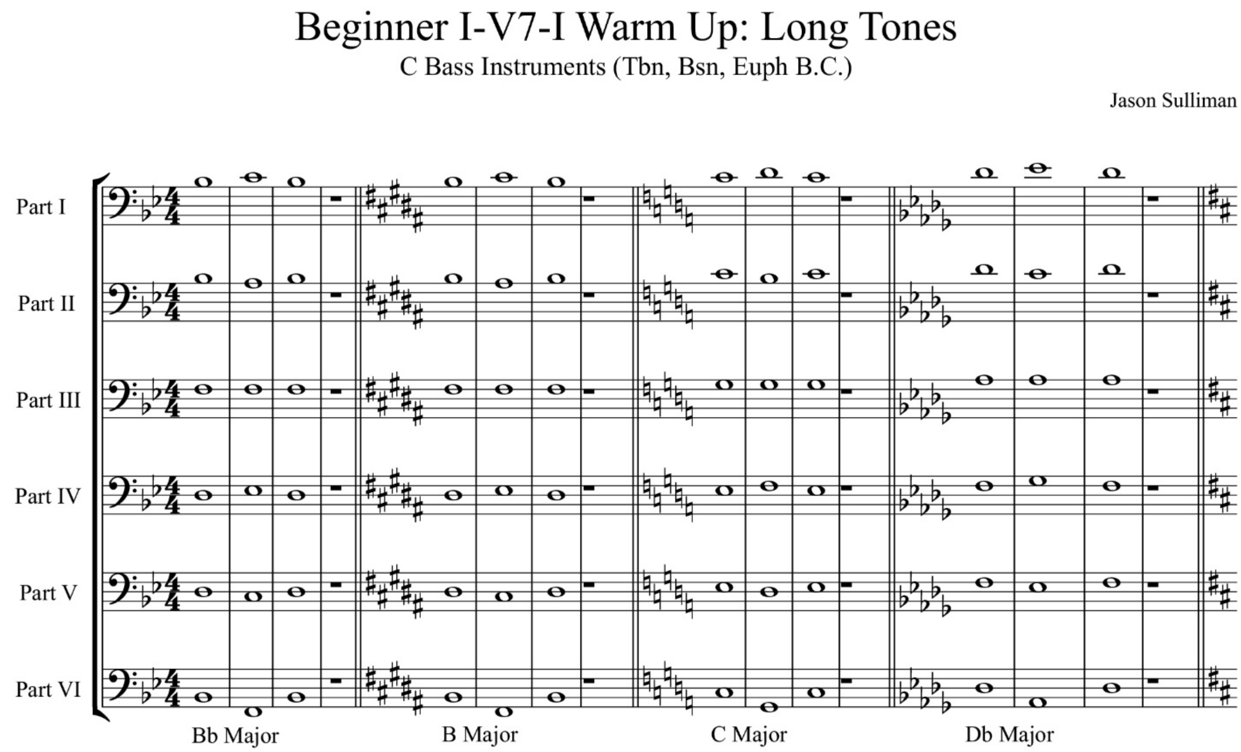

Figure 15. Beginner I-V^7-I Warm-Up: Long Tones

Figure 16 is an example of long tones that utilize the tonic (I) and subdominant (IV) chords as a harmonic framework:

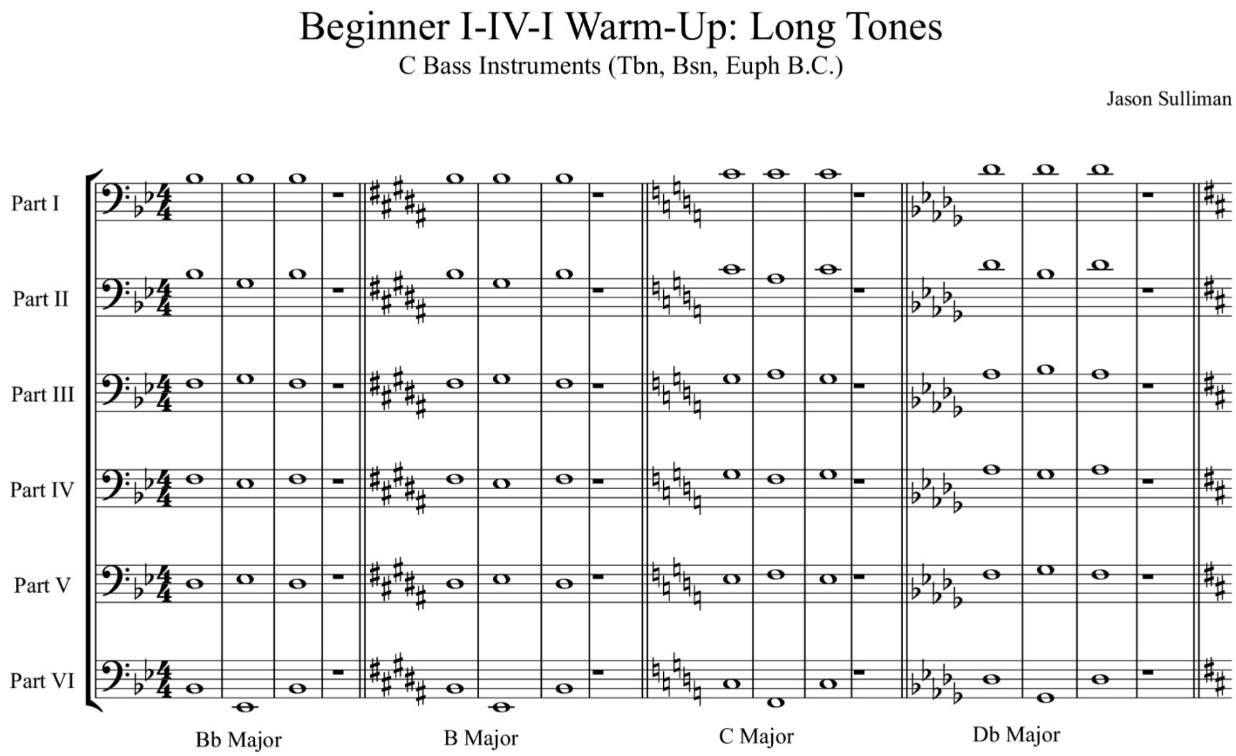

Figure 16. Beginner I-IV-I Warm-Up: Long Tones

Figure 17 is an example of long tones that utilize the tonic (I) and submediant (vi) chords as a harmonic framework:

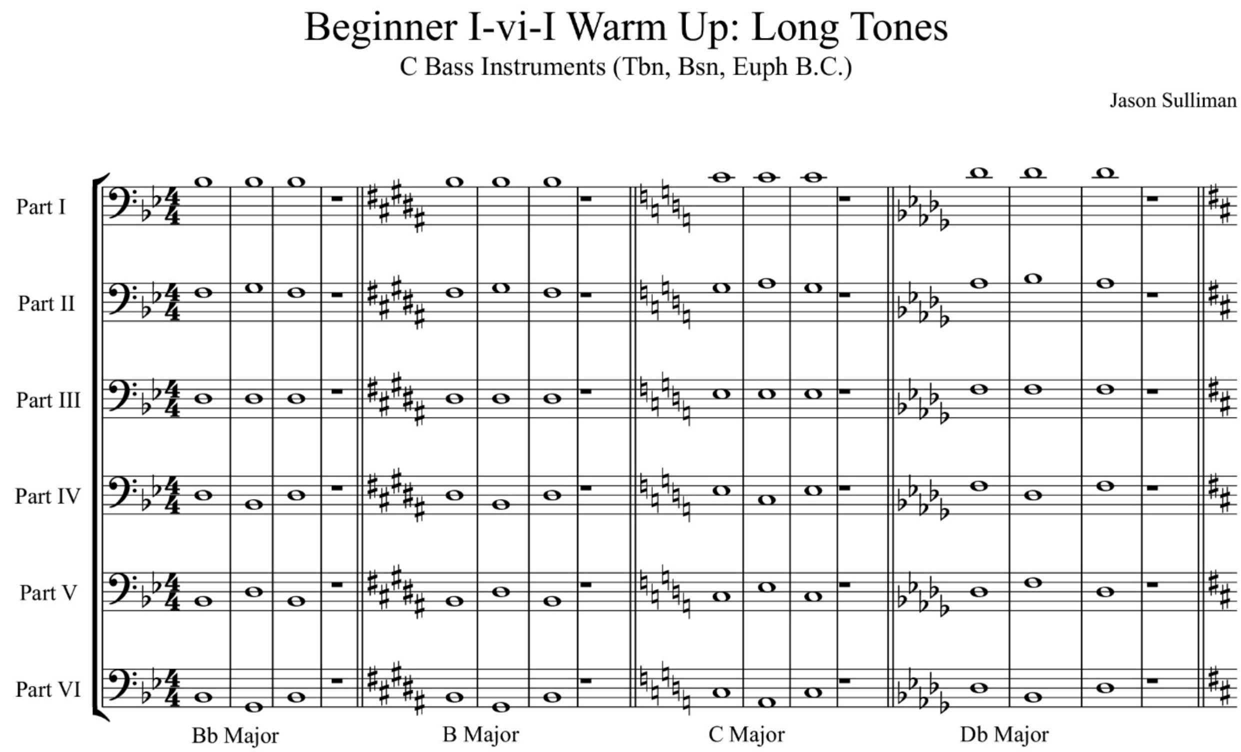

Figure 17. Beginner I-vi-I Warm-Up: Long Tones

The above three chord progressions are built using the most common chords found in Western harmony as the backbone (I,IV,V, and vi), and create these chords through the combination of different parts playing common intervals found in diatonic scales (2nds, 3rds, 4ths, and 5ths). Though the intervals found here are similar to the Remington Long Tones, they are structured here in a way that that mimics Western music on hierarchical levels, which creates the opportunity for musicians to develop ease and control in higher levels tonality such as phrasing, voice leading, and cadence. Additionally, this structure allows performers to develop mastery of pure harmonic intonation, which is still widely used in universities and orchestras that perform Western classical music.

Additional benefits of using chord progressions for long tones.

Each Part within the above three chord progressions utilizes a common interval that is then performed within each key. For example, in the I-V7-I Chord Progression, Part I uses an ascending major second to create a series of patterns that navigates between the root of the tonic chord and the 5th of the dominant chord. By repeating this pattern in several different keys (ascending or descending) a performer can start to develop autonomous control of this common example of voice leading. Additionally, the performer can develop the ability to tune these chords using the principles of pure harmonic intonation. As mentioned earlier, phrasing becomes an integral part of the exercise. These are examples of full integration of a comprehensive music theory curriculum where students apply basic principles of music theory to their daily playing. Most applied curricula stress the importance of understanding information presented in music theory courses. This method of playing basic long tones provides an opportunity for students to fully master both theory and ear-training skills while they practice.

Control for blocking effect/contextual interference. Most beginner band classes in the United States use method books that focus on flat key areas that are 'friendly' to B^b trumpet, F horn, B^b trombone/euphonium, and BB^b tuba. A majority of beginner method books rarely if ever venture beyond a few flats or one sharp as a key area in order to streamline the feasibility of the method to a broad, heterogeneously-grouped instrument class that will experience a general level of success in these key areas relatively quickly. Students spend months (in worse cases, years) associating values and meaning to certain visual symbols (e.g. music notation) but do not get exposed to all of the symbols that they will need to know to be successful in later years. As a specific example, a beginning trombone student might see a "middle f" in their book hundreds of times and never be exposed to f# or f^b since those notes do not exist within the key areas of F, B^b, and E^b. The middle f is on the 4th line of the bass clef staff, and students develop an association between seeing that visual symbol, and moving their arm inward to bring the slide to first position where middle f is played. After hundreds of trials and months of entrainment, a student might then be exposed to the key of g, where a note on the 4th line is now f# (due to the key signature) and requires extension of the arm to bring the slide out to 5th position. This is almost the exact opposite movement as the response for f natural. Based on research presented in part one, it is possible that the number of times a student will need to be exposed to the second visual symbol ($f^\#$) could be as high as 50 times as many times as the first symbol was presented. A student that learned their instrument in a band program that avoids sharp keys for two years will potentially be dealing with issues related to sight-reading far after their college training.

By taking the same example of a simple chord progression that was used earlier (Figure 15 shown again here), we can avoid this blocking effect with visual symbols of music notation.

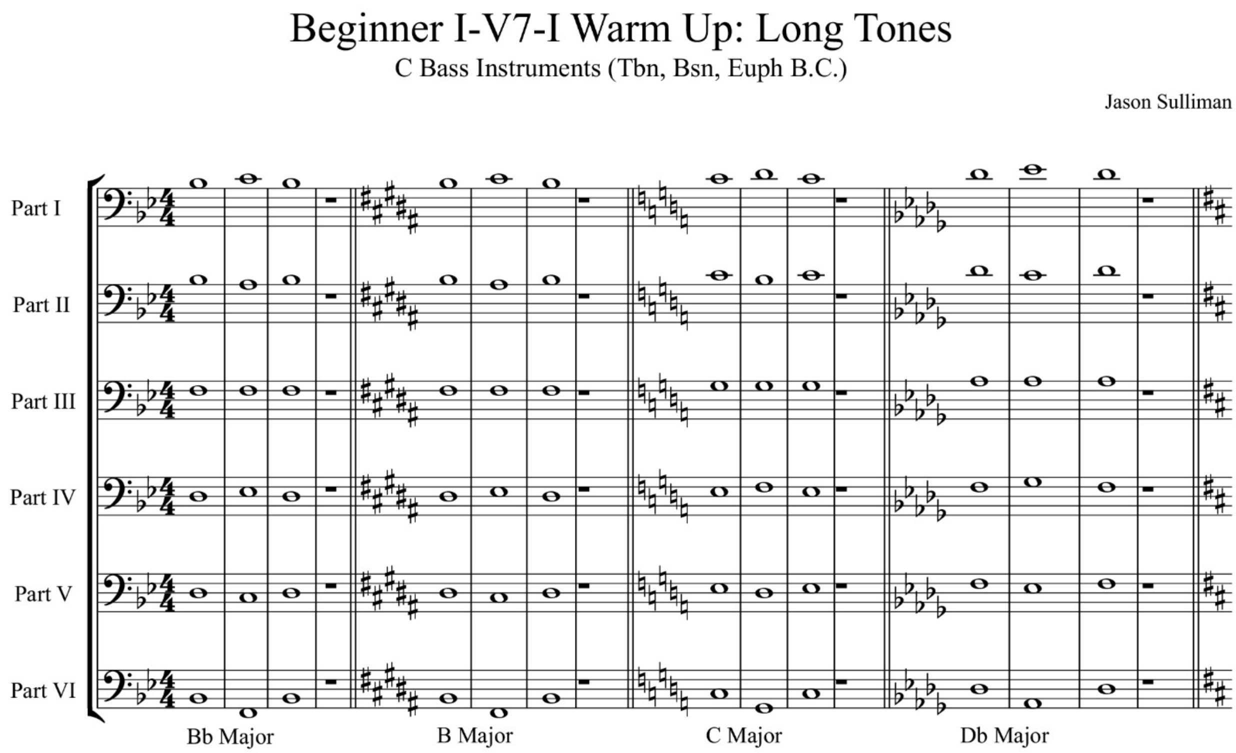

Figure 15. Beginner I-V^7-I Warm-Up: Long Tones (Repeated)

Notice that in Figure 15, notes are first presented in the key of B^b. The very next set of notes that a student learns is the key of B, which visually looks identical to the B^b version with the exception of a key signature. For example, part III starts with an f natural in the key of B^b. The very next note that is introduced is $f^\#$ in the key of B. A beginning student would immediately learn two associated meanings for the same visual symbol, which would more effectively lay a foundation of success with reading music notation in the Western tonal tradition.

Flexible difficulty. Similar to Remington, these chord progressions can be performed as a group exercise and allow for heterogeneous instrumentation. One of the major differences between the two exercises, however, is the added possibility of creating a flexible level of difficulty for individuals. With the chord progressions, scale patterns and arpeggiations can be added that follow the same harmonic progression and enable more advanced players to bridge the gap between basic chord outlines and typical patterns found in the classical repertoire. Here are some examples (shown in Figure 18) of advanced versions of chord progressions that can be played simultaneously:

Figure 18. Examples of Flexible Difficulty Exercises for Harmonic Long Tones

In Figure 18, part I will present considerable challenges for an average high school player as the parts ascend through different keys. This part resembles Lesson V in the Caruso Method, which is a common method used to help develop the upper register (Caruso, Graham, & Booth, 1969). Part II is a disjunct arpeggiation that passes through the tonic and dominant 7th chords, which creates considerable challenge for even a professional player, especially if performed in twelve keys. Part III does not change notes, and would work well with a beginner. Playing through ascending keys will slowly start to introduce a chromatic scale and will help develop a beginner's upper register. Part IV is a great example of a common half-step resolution (the b7 resolving down by step to the 3rd of the tonic) that helps introduce chromatic half steps as well as enharmonic equivalents. Part V mimics a typical scale pattern (the first five notes of a major scale) which is a common scale pattern for high school students to develop. Part VI represents the bass line of the chord progression which is particularly important for bass instruments to develop.

Contemporary harmonic context: stacked intervals. An effective complement to the above-mentioned chord progressions is the use of even intervals. As mentioned in part one, different contemporary composers utilized specific intervals to create a modern harmonic context from which to create new sounds. Here is an example (Figure 19) of the eight smallest intervals used to create a simple 5-note line (note: enharmonic notes are used when favorable):

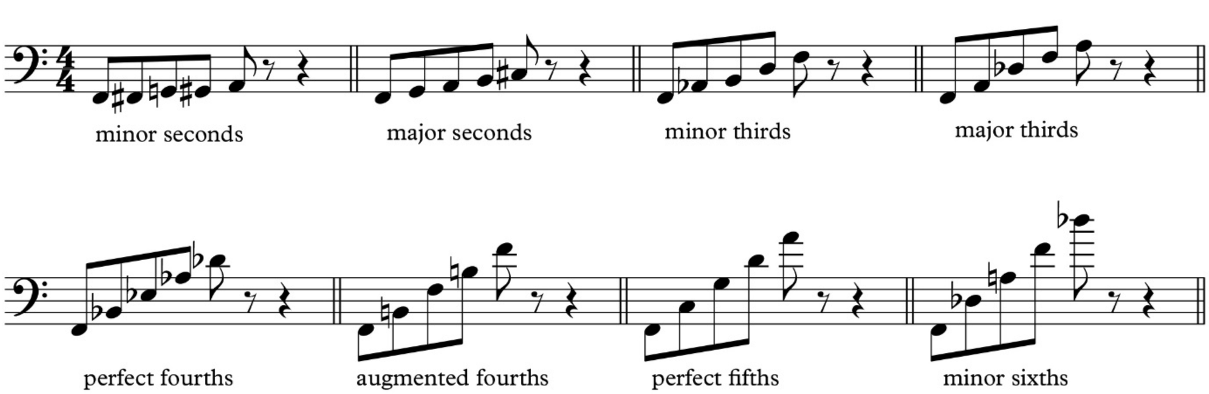

Figure 19. Stacked Intervals

Performers should develop a familiarity with stacked even intervals not only to become familiar with the different emergent patterns found in these intervallic examples, but also to gain greater facility over a wider range (discussed later).

21st-Century Exercises for development of Embouchure

Brass instrumentalists have to navigate a working range of the instrument that is usually between 2.5 and 4.5 octaves depending on the instrument and the context. Brass players need to develop the ability to navigate as large of a range as possible and do so with ease and efficiency. Though published research through peer-reviewed journals is non-existent for embouchure variability within subjects (outside of pathology) it is reasonable to apply concepts addressed in part one regarding anatomy and physiology of the embouchure and deduce that an individual will have several different embouchures or settings of the mouthpiece that can each serve a specific part of the range. These embouchures or settings will have overlap and therefore will be highly context-dependent (see Chapter One). Rather than developing an embouchure (or specific setting of the mouthpiece), one should focus on developing the ability to easily play the entire working range of their instrument. The byproduct of this development will be smooth changes between multiple embouchures or settings and robust flexibility to navigate all registers of one's working range.

In order to create effective exercises for developing one's embouchure, one must consider the following aspects of context: First, the starting point within the range. Second, limiting the focus of the exercise to notes within a single phrase of breath. Third, developing fast technique in order to cover a greater range on a single breath and limit the time for shifting.

Context of starting point. When working on range, the starting point within the range becomes a crucial factor. Most exercises start where they always have: in the middle register. We learn notes in the middle register as beginners and for many players everything starts in the middle register even as they progress. Warm-ups often start in the middle register, and exercises to develop range also start in the middle register primarily out of habit. The problem with starting in the middle register is this range may be performed using a particular embouchure or setting that might not be optimal for playing in the extremes. The challenge occurs when one tries to play into the extreme high or low register from this starting point. It is possible that a player has avoided developing a functional embouchure for the upper register, and instead of developing one, they keep trying (unsuccessfully) to widen the functional range of an embouchure or setting suited for middle register playing. Instead players should also treat the goal note as a constant, and develop range by widening the range from which one can reach that goal. For example, if "high B^{b}" ($B^{b}4$) is the goal, then starting close to $B^{b}4$ and working up to it should be the starting point. F4 might be a good starting point. As security is gained from F4, then the player adds notes so the exercise starts from E4, D4, etc. and the challenge becomes reaching $B^{b}4$ from a lower starting point. By changing the place within the range where one starts can help develop an embouchure or setting better suited for development in an extreme part of the register. Figure 20 is an example of a high range exercise that focuses on the changing of the starting note:

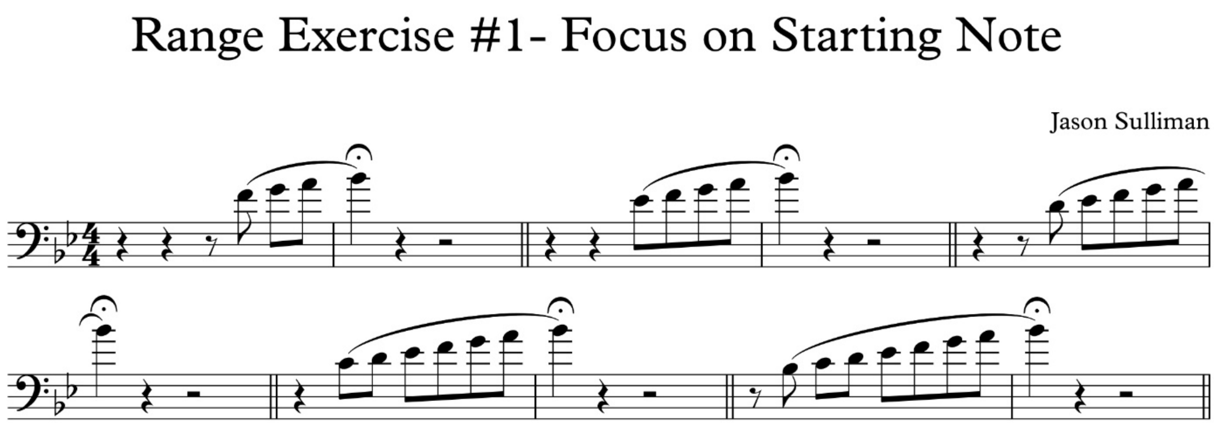

Figure 20. Range by 5's- Focus on Starting Note

Individuals can determine what note makes the most sense as a goal note as well as a starting note. Over time, the starting note is moved further away from the goal note to increase the range played.

On a single breath. In order to control for shifting of mouthpiece placement (which may cause unwanted switching between different settings), range can be productively addressed only with exercises and passages that are performed on a single breath. Obviously breaths will need to be taken, but every breath needs to be specifically accounted for within the goals and context of the exercise. One way to develop a range-building exercise that accounts for breaths as the primary environmental constraint is to develop an exercise that adds difficulty by shifting where breaths occur. Many players feel they need to take a breath before certain phrases in order to 'get a good setting'. This is commonplace among all levels of musicians, however, it masks a larger issue that will need to be addressed in order to achieve the highest levels of consistency and success within navigating a large range.

Range by 5's. Here is an example of a range-developing exercise that keeps the concepts of starting point, goal note, and breaths as the main focus. In this exercise (shown as Figure 21), phrases are divided into five notes with one note overlapping in each group of five (the first and/or last note is repeated in adjacent groups of five). First a total range is determined with the highest note (or lowest note) being the goal. Then groups of five notes are configured such that the exercise reaches the goal note. In this example, D4 is used.

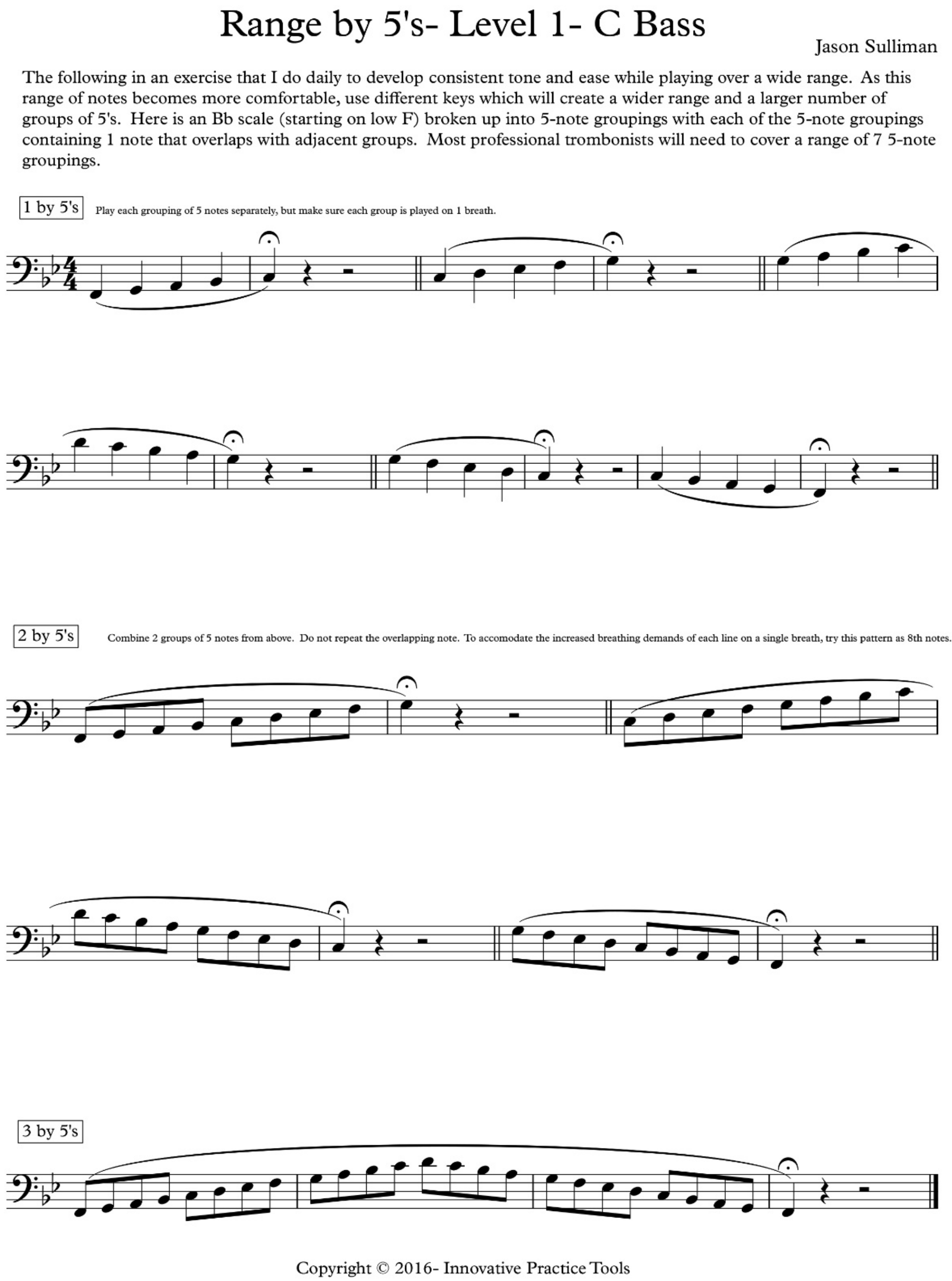

Figure 21. Range by 5’s- Level I

For a typical beginner trombonist’s range, three groups of five notes (totaling a range of a major 13th) is a reasonable goal. As one develops control over this range, they can add a 4th grouping of five notes, which increases the total range to two octaves plus a major third, shown below in Figure 22:

Figure 22. Range by 5's Exercise- Level II

Figure 22 is presented in the key of F while the first version was presented in the key of B^b. Any key can be utilized while keeping the goal note the same (or a half step away). A variety of keys should be utilized to maintain a balance of familiarity within different harmonic contexts. Range by 5's can also be further expanded to accommodate an even larger range as players become more advanced.

Fast technique. In order to increase a performer's working range of the instrument within a single breath, exercises must be created that can be played relatively quickly. It is reasonable that a more advanced player needs a bigger range, but also has greater technical abilities to play exercises more quickly, so this should not be a huge concern. Nevertheless players will need to develop speed in order to perform exercises that are appropriately addressing the development of range and the efficiency of navigating multiple embouchures or mouthpiece settings. By taking the two examples of Range by 5's above, it is obvious that the tempo of the first example is far less critical to the success of playing the entire last phrase on a single breath (25 notes) as it is with last phrase of the second example (33 notes). As the exercise is expanded, the last phrase, which encompasses the entire range will be made up of a greater number of notes and therefore a greater speed will be required to play the entire phrase on the same breath.

Even intervals. From the standpoint of embouchure and range, it is fortuitous that even intervals can be used to develop exercises that navigate a larger range of the instrument through wider leaps. Using the previously introduced example of even intervallic patterns, it is obvious to see the increase in total range while minimizing the increase air demand of the phrase. If a performer plays five notes that are a minor second apart, then the total range will be a major third. If a player plays five notes that are all spaced evenly at a major second, then the total range becomes a minor 6th. The larger the interval, the more quickly the total range of a phrase increases. The earlier example of even intervals (Figure 19) is presented again here:

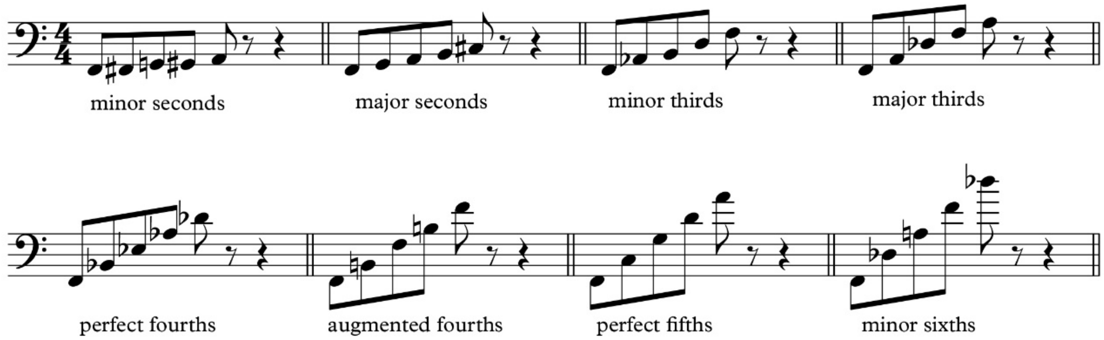

Figure 19- Stacked Intervals in 5-Note Patterns (Repeated)

By developing fluidity and ease using these patterns over variable starting notes, one can create hundreds of different exercises to address range in a contemporary harmonic setting.

Advanced embouchure/range- broken intervals. A more advanced version of even intervals, called "Broken Intervals", requires players to alternate ascending and descending while using the same group of notes. Here is an example of broken intervals (shown as Figure 23):

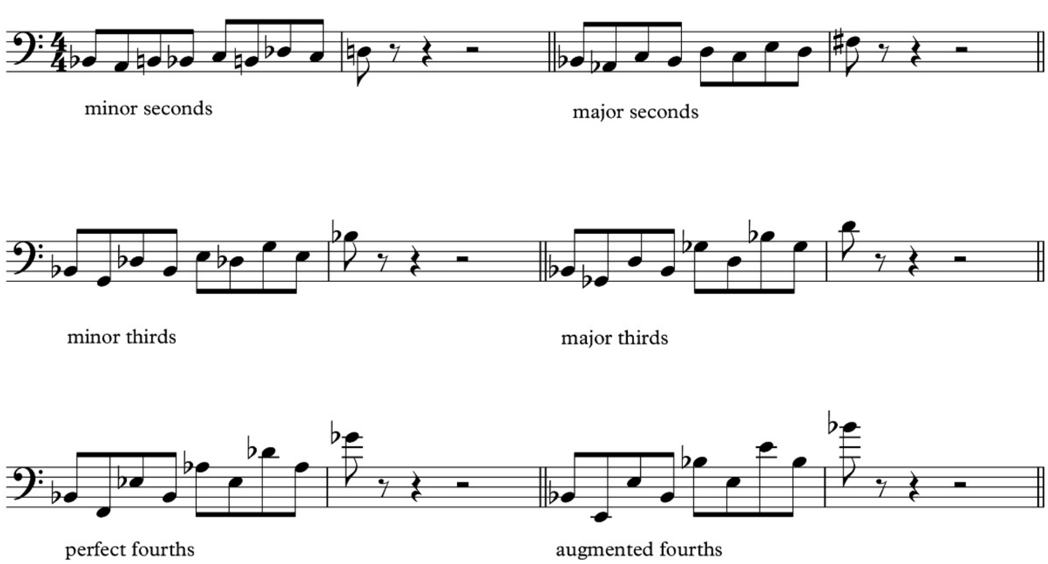

Figure 23. Broken Intervals

Summary

Musicians will continue dueling with the paradox between tradition and innovation. The concept of consistency is built on the premise of performing with the same level of quality and accuracy every time. The road to consistency will always be equally as tempting as experimenting with new methods. When one adopts new techniques, they have the potential to improve efficiency and/or quality. They also have the potential to cause no difference, delay progress, or as a worst-case scenario, actually degrade one's playing ability. New methods have to overcome the disproportionate level of skepticism since what makes them new is that no one is currently using them. The road of music pedagogy has always been paved with anecdotal testimonials within the apprenticeship system of mentorship. The irony exists in this system as every aspect of current brass pedagogy was at one point a novel idea by someone and was compared to conventional wisdom of the time.

Given that the pace of scientific discovery is increasing in the 21st century, it would stand to reason that adaptations and changes to current brass pedagogy in the 21st century would show a similar increase of pace, however many seem reluctant to adopt methods that aren't explicitly supported by the top performers of our field. Hopefully this paper offers insight into several different directions that brass players can apply concepts discovered in recent scientific inquiry. It is by no means meant to provide an ending point to the journey. On the contrary, the concepts introduced here should be interpreted a point of departure for the advancements of 21st-century pedagogy.

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Appendix- Limitations on fMRI and EEG Measurement

There are several limitations to fMRI measurement that need to be taken into consideration when grappling with fMRI findings. First, traces are put into the blood stream and it is the blood stream that is measured in the brain. This is a **BOLD** (Blood Oxygen Level Dependent) measurement and unfortunately it takes about six seconds for changes to happen. Even if activating a region of your brain were compartmentalized, it takes about six seconds to turn on the switch. This makes measurement difficult because it is a rough estimate of time that passes. Countless forms of contamination can occur within that time. We can act as a closed loop system by evaluating changes almost immediately. This will have an effect on brain activation. Second, fMRI requires the use of a large magnet that spins around a subject's head. The subject must lie down on a table and the head is immobilized. This method of measurement removes the agent from its natural environment which can have significant changes on brain activation. Not only are tasks limited to what can be done while lying down with an immobilized head, but this posture has an effect on how we perceive and act within our environment. Third, fMRI measurement needs to be specifically planned in advance. The entire brain is not measured but instead small slices are recorded for activation. Scientists must predict what regions are most likely activated and focus on those regions during examination. Exploratory measurement is largely avoided due to technology and resource constraints. This severely limits scientist's ability to stumble upon new and interesting patterns of brain activity that might shape our understanding significantly. Lastly, scientists are reluctant to subject people to prolonged exposure to fMRI. Everything is measured in small does with very little (if any) ability to measure longer effects or changes in organization of brain activity over time. As scientific discovery sheds more light on the variability and refinement of neurological organization, fMRI must be further marginalized in its current utility. Until progress can be made to make a portable measurement device that enables subjects to move more freely within an environment and be measured for a prolonged periods of time with greater sensitivity and scope, fMRI must be considered only a small tool in enabling scientists to answer complex questions regarding brain activation during thought and action.

Though EEG is somewhat complementary to fMRI measurement, it also comes with limitations, specifically for experiments aimed at measuring timing tasks. First, EEG uses surface electrodes, which provide a great 'reaction time' to activity. Measurement can happen after only a few milliseconds, compared to fMRI's 6-second rule explained above. When measuring timing, however, regions like the cerebellum and basil ganglia have been shown to be involved in human activity involving the coordination of movement over a temporal constraint. Since EEG measures only surface-area with significant accuracy, it is not helpful when conducting studies involving measurement of activity in the deeper regions of the brain.