The Effects of Handedness in Percussion Performance

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Abstract

This thesis unites the fields of laterality and music by presenting two studies on handedness in percussion performance. Handedness is a subcategory of laterality, and is generally concerned with asymmetries found within the human body. One of the most fundamental divisions exists between the left- and right-sides. Previous research has shown that these differences develop early in body, and have a considerable and far-reaching influence over the way we interact with the world [1] [2]. Given that percussion performance utilizes bi-manual action, this instrumental category was investigated to observe how handedness and musical gesture affect one another.

Specifically, the work contained within this thesis focuses on the bi-manual actions of percussionists within a musical context. First, a review of laterality research is presented including important studies on bi-manual and musical work. Laterality is an interdisciplinary subject, with a large number of analysis methods and theories. Some of the most influential literature is reviewed in chapter 2, before two preliminary studies of handedness in snare-drum and timpani performance are presented.

After the initial look at the effects of handedness in percussion, two thorough experiments on the effects of handedness on the timpani are presented. The first study (chapter 3 focuses on the gestural differences between the left- and right-hands when performing a neutral (symmetrical) bi-manual task. This is done in an effort to see how one's gesture is affected when no music is being performed. The second study evaluates how participants left- and right-hand performance frequency is related to internal timing and the metric function of musical notation. This experiment utilizes sight-reading to see how the participants issue responses with each hand. These studies are presented within the context of the literature review and preliminary studies in order to frame this work within the larger field of laterality. The overall findings suggest that handedness is responsible for both functional (performance-based) and formal (trajectory-based) differences in percussion performance gestures.

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Contribution of Authors

Thesis regulations require that contributions by others in the collection of materials and data, the design and construction of apparatus, the performance of experiments, the analysis of data, and the preparation of the thesis be acknowledged.

Some of the content of chapter 2 was originally published in the 10th International Symposium on Computer Music Multidisciplinary Research [3]. My supervisor, Marcelo M. Wanderley, co-authored the paper. This paper was reformatted and edited to fit the narrative of this thesis. Furthermore, the content of chapter 3 was originally published in the first ever International Workshop on Movement and Computing [4]. Marcelo M. Wanderley was again my co-author, along with Fabrice Marandola, and it has also been re-edited for this thesis. Lastly, the motion capture data from the chapter 2 analysis was produced by Alexander Bouënard [5].

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List of Acronyms

PF	Preferred Hand
NP	Non-Preferred Hand
LH	Left-Hand
RH	Right-Hand
BPM	Beats Per Minute
NT	Neutral Task
SR	Sight-Reading
CIRMMT	Center for Interdisciplinary Research in Music, Media, and Technology
IDMIL	Input Devices and Music Interaction Laboratory
LQ	Laterality Quotient
EHI	Edinburgh Handedness Inventory
AHQ	Annett Handedness Questionnaire
WHQ	Waterloo Handedness Questionnaire
WBT	Wathand Box Test
APT	Annett Pegboard Task
GPT	Grooved Pegboard Task

Chapter 1

Introduction

This chapter serves as the introduction to the thesis, *The Effects of Handedness in Percussion Performance*. Since the general nature of the research contained within this document draws from several different disciplines, this introductory chapter covers the major topics contained within, which includes the fields of: Laterality, Percussion Performance, and Motion Capture/Gesture Analysis. These topics provide the theoretical context for the experiments and results presented in chapters 2, 3, and 4.

1.1 The Left and Right

Throughout human history, the left-right dichotomy has served as the one of the most important and useful metaphorical tools for explaining comparisons and contradictions. By referring to a distinction based on anatomical orientation (*i.e.* the left- and right-sides of the body), the addressed subjects become viscerally understandable. Aristotle considered the left- and right-sides to be fundamental opposites and included the two in his Pythagorean table of *Ten Opposites* [8] (Table 1.1).

While the associations governing the separation of elements in either column are most certainly erroneous (*e.x.* grouping female with bad, darkness, moving), the distinction between the left- and right-sides is certainly clear. Furthermore, the left-right dichotomy can be seen in cultures throughout the globe, unaffected by time, culture, and geography [2].

For some time, it has been known by mankind that there is a fundamental division between the left- and right-sides of the body. Unfortunately, due to the lack of technology

Table 1.1: Aristotle's Pythagorian Table of Ten Opposites

Unlimited	Limited
Odd	Even
Many	One
Left	**Right**
Female	Male
Moving	Still
Bent	Straight
Darkness	Light
Bad	Good
Oblong	Square

and reliable scientific process, the origins of the exact nature or meaning of this division remained a mystery for centuries. Myth and cultural bias trumped any empirical evidence regarding the origins or implications of the left and right. In fact, it has only been in the last several decades, beginning with Woo and Pearson's insightful conclusion to their 1927 study [9], that meaningful contributions have been made towards a greater understanding of the left-right dichotomy.

1.2 Laterality

Our current understanding of the left-right dichotomy has developed beyond the realms of myth and superstition, and is now incorporated into a larger field of study dedicated to researching the differences between the left- and right-sides. This relatively new interdisciplinary subject is called *laterality*.

In a seemingly endless number of ways, we are affected to some degree by *lateralisation*. This is generally defined as the preference of one side of the body for a particular function [10]. The field of laterality is multidisciplinary in nature, stemming from studies in psychology and neuroscience [11], and further applied to reviews of its effects in the arts and culture [12]. Common sub-categories of laterality include studies in handedness, footedness, and the hemispheres of the brain.

With such widespread influence over our bodies, one can easily begin to wonder how laterality affects our movement strategies. The subcategory of handedness is one of the most popular points of inquiry, and has included studies attempting to understand some of the most basic questions regarding the human mind and body, including how prenatal movement can predict traits later on in life [2]. Among these questions lies the search for the cause of human hand-preference. It is generally agreed upon that we live in a right-hand dominated world. Thus, when we classify ourselves in terms of handedness, we employ the aforementioned timeless dichotomy: those who exhibit sinistral (left-handed) preferences, or dextral (right-handed) preferences.

1.3 Percussion Performance

Because of the bi-manual nature of percussion performance, this instrumental category is ideal for observing the effects of handedness in music.

On the surface, understanding the nature of percussion performance seems quite simple. A percussionist strikes an instrument with their hands or with a stick, and the object sounds accordingly. With a single stroke, any object can become a percussion instrument; perhaps this is why percussion instruments have been traced as one of the earliest musical instrument families in human history [13]. Despite the low entry fee [14] that percussion instruments offer their performers, the actions that execute the performance gestures involve complicated dynamic relationships between the performer's body and instrument(s) [15]. Godøy describes that what may be seen as a single performance action can contain many *co-articulative* elements within it [16]. The notion of *co-articulation* demonstrates that intensive efforts are needed to fully understand the nature of musically-influenced gesture.

As an academic research subject, percussion has been quite popular in neurological and psychological studies. For example, recent research has covered a wide range topics including investigations of the mental encoding strategies used by expert performers [17], as well as the generation of listening profiles of percussionists in order to reduce hearing loss [18].

1.4 Motion Capture

Motion capture systems provide researchers with a powerful tool for observing and analysing movement. Although the technology is relatively new, with many different methodologies, motion capture is extremely popular in many fields of study ranging from structural engineering to computer animation. The research conducted in chapters 3 and 4 relied on an optical passive marker system designed by *Qualisys Motion Capture Systems* [19].

In this system, several specialized motion capture cameras track the movement of passive markers. These motion capture cameras emit and receive infra-red light, which is reflected back into the camera lens by the passive marker. Each camera is outfitted with an array of extremely bright infra-red LEDs which encircle the lens. A passive marker, coated with a reflective material, is recorded by the cameras. When three or more cameras spot the reflection of a marker, its position in three-dimensional space can be calculated.

Developed exclusively for research purposes, optical motion capture systems have practical uses in medical, engineering, and commercial projects [20]. Most medical applications stem from rehabilitative research, where motion capture is used to study the development of an individual's recovery. In engineering, the very same systems are used to observe the performance of a particular structural design. Finally, more affordable motion capture systems (relying on a mixture of computer vision and infra-red) have become commercially popular in modern video game systems.

Recent advancements have resulted in the development of marker-less motion capture systems, which rely on computer vision. In this case, the computer recognizes the shape of the subject being recorded. While the ecological value of a marker-less motion capture system is appealing, the lack of flexibility regarding virtual motion capture marker locations was not practical. Marker-less systems rely on a recognizable model, which currently only includes a single human body (without any musical instruments, or sticks for that matter).

1.5 Research Motivation

A quick search for studies involving laterality and music will yield an enormous number of studies. In fact, a few pertain to percussion and handedness [21] [22], and will be discussed in detail in the next chapter. Motion capture technology is quickly producing a large number of interesting studies. It is therefore surprising to see that little to no literature has employed motion capture with regards to handedness in percussion performance.

Because of the complicated nature of percussion and due to the vast instrumental scope of the percussion family, studies of percussive gesture have generally been limited in focus to a particular instrument.

This thesis aims to address the issue from the perspective of a performer. The analysis methods will specifically focus on the practical performance implications for the player.

Understanding the physical relationships between performer and instrument are crucial for the advancement of technology in gestural recognition, data acquisition, gestural modelling, and instrument design [23] [24] [25]. Furthermore, the development of a framework for approaching handedness in percussion performance will provide a powerful pedagogical tool for instructors and students alike.

1.6 Hypothesis and Thesis Structure

Given the fundamental nature of laterality in human movement and the manual dependency of percussive gesture, it is hypothesized that there are strong links between the two. Theories on handedness can provide invaluable insight in describing observations of percussionists, and this thesis is designed to address how and where these links reside within our current understanding of laterality.

In order to establish a theoretical framework linking the three main topics of this thesis (motion capture and gesture analysis, percussion performance, and laterality), the chapter organization of this thesis will proceed as follows:

1.6.1 Chapter 2 - Handedness, Symmetry, and Percussion Performance

This chapter will specifically focus on relevant research concerning handedness and percussion performance with the goal of developing a sufficient background for describing the results in the experimental chapters. Because of the diversity of research topics in laterality, a useful summary of the origins and theories regarding this field will be presented here.

Once the relevant background has been introduced, two generalized examples suggesting the effects of handedness in percussion performance are presented. These examples are framed in relation to the notion of symmetry in percussion performance. Symmetry is discussed in terms of physical instrument design and the performance technique used by percussionists.

1.6.2 Chapter 3 - The Effects of Handedness in a Neutral Task

After establishing the necessary theoretical framework for handedness in percussion performance, chapter 3 presents a close look at the motion capture data of 6 percussionists performing a bi-manual symmetrical task. This experiment was designed to determine what natural tendencies the hands reveal when the generation of musical material is not required. The participant's data is analysed in relation to the observable differences in trajectory between the left- and right-hands.

1.6.3 Chapter 4 - The Effects of Handedness in Percussion Sight-Reading

While the neutral task presented in chapter 3 suggests that the effects of handedness can have a strong influence over the gestural approach of a performer, chapter 4 looks for handedness' presence in the context of a musical performance. An original sight-reading score is used in the experiment to challenge the participant's time keeping strategies. Because the attention of the participant is fixed on the score, this experiment allows for the observation of the automatic stick-ordering choices of the participant. The results of the participant's performances are then analysed in relation to the score in an attempt to find a correlation between handedness and the rhythmic function of notated music.

1.6.4 Chapter 5 - Conclusion and Future Work

With the main experimentation and results detailed in chapters 3 and 4, this final chapter restates the impact of the findings contained within this thesis. In addition, the research is contextualized in terms of suggestions for improvements, while providing a road map for future work.

Chapter 2

Handedness, Symmetry, and Percussion Performance

The main topics of handedness (a subcategory of laterality), percussion performance, and motion capture are each interdisciplinary in nature. In order to contextualize the experiments in chapters 3 and 4, this chapter will focus on relevant topics and previous research, while providing two preliminary studies on handedness in percussion performance.

2.1 Accessing Handedness

To fully understand handedness, it is necessary to become acquainted with its origins. While it is a widely known fact that the majority of humans tend to prefer their right-hand when performing a manual task, most people are unaware that this phenomenon is considered to be unique among humans [1]. The distribution of handedness in humans fits along a bell curve which, if it were shifted to the left, would match the distribution curve of other mammals (where the center of the bell-curve is located over 50%). Estimates have suggested that right-handed people account for roughly 88% of the population [26]. Of course, this does not declare that handedness is rigidly bound to those numbers. Handedness, and laterality for that matter, refuses to conform to the convenience of dichotomization. Rather, handedness can be considered as a spectrum, with a unique mixture of preferences for each individual.

Two outstanding publications have greatly shaped and contributed towards a greater understanding of laterality today: *Handedness and Brain Asymmetry* by Marian Annett

[1], and *Human Laterality* by Michael Corballis [2]. Both texts contain a comprehensive view on the many salient topics influenced by human lateralisation. While Corballis' review investigates lateralisation in humans from a number of contexts involving the entire body, Annett focuses primarily on handedness, its origins, and classification methods.

2.1.1 Human Laterality

Human Laterality, like *Handedness and Brain Asymmetry*, contextualizes and summarizes decades of previous research in the field of laterality across a variety of different disciplines. The opening chapter begins with an interesting look at the various ways laterality (predominantly handedness) has been integrated into human culture and myth. The apparent ubiquity of laterality across global cultures throughout history establish the notion that this seemingly simple fact of human body has complex origins.

The issue of determining the effects of handedness' biological origins versus its cultural origins has always proved to be quite difficult. As will be described in section 2.2, classifying handedness is not as simple as one might think. Corballis does well to separate the two while indicating that handedness has deep biological origins, accounting for the widespread influence of right-handed dominance across different cultures.

Further chapters examine the development of the brain, and how laterality can be observed in the womb. Corballis describes several interesting theories for the origins of handedness, including the theory that the development of speech in the left-hemisphere led to increased dexterity in early human populations.

2.1.2 Handedness and Brain Asymmetry

Marian Annett has long been considered one of the most important pioneers of the field of laterality. During the 1970's and 1980's, a vast swath of studies put forth by Annett rapidly broadened our understanding of handedness' origins and classification. With the first edition appearing in 1985 as *Left, Right, Hand and Brain: The Right Shift Theory*, Annett provided the field of laterality with a comprehensive and authoritative text on handedness. This body of work has been updated through-out the decades and currently exists as *Handedness and Brain Asymmetry* [27].

One of the primary messages presented by Annett is concerned with the spectrum of handedness. The term *right shift* was coined by Annett and describes the distribution of handedness in the human population described in this section's introduction. Annett is responsible for pushing for a change from the dichotomous view of handedness to the current accepted theory of the continuum. As stated in *Handedness and Brain Asymmetry*, Annett proclaims that the "essence of handedness cannot be assumed "due to the extreme variability of its nature. One's genetics and cultural surroundings blend together in what eventually becomes the habitual preferences for a given task. These preferences are dynamic as well, which can make determining the handedness of an individual a difficult task.

2.2 Tools For Classification and Analysis

Laterality research has generally employed two different methods for studying handedness: 1) Questionnaires and 2) Performance-based testing. While each method comes with its own advantages and disadvantages, both attempt to put into quantitative measures the degree of one's handedness. For many years, inventory-based questionnaires were the most popular tool for handedness classification [28], but because of several issues regarding the reliability of their evaluation, observable performance-based testing has become the preferred method for classifying and analysing handedness.

2.2.1 Questionnaires

Because of the ease in developing and distributing handedness questionnaires, there have been dozens of customized editions spread throughout the laterality literature. Questionnaires inquire about the participant's habits and tendencies regarding hand use in a given task. The ultimate goal of these exercises is to come up with a quantitative metric for measuring the extent of one's hand preferences. Among the most popular and influential were: the *Edinburgh Handedness Inventory* by R.C. Oldfield (1970) [29], and the *Annett Questionnaire* by Marian Annett (1970) [30].

Questionnaires: Annett and Edinburgh

The Edinburgh Handedness Inventory and the Annett Questionnaire, despite being two of the earliest inventory based handedness assessment methods, have nearly monopolized laterality research of the past several decades [28] [31] [32].

The Edinburgh Handedness Inventory (EHI) [29], initially published in 1970 by R.C. Oldfield, was a questionnaire which came in 10- or 20-item editions. Each edition listed items of inquiry regarding one's hand preference for a given object or action. The objects and actions listed were terse in nature (*e.x.* writing, hammer), and required the participant to select the left-, right-, or both hands as their preference for the item in question. The answers were recorded in a column to the left of the question and were scored as + for a preference, ++ for a strong preference, and a + in each column for equal preference. The marks for the left- and right-sides were tallied up in order to produce a *Laterality Quotient* (LQ). After the addition of all the +'s for the hands are counted, the sum for the left is subtracted from the right, divided by the total number of +'s, and multiplied by 100. The resultant LQ scores can range from -100 (completely left-handed) to +100 (completely right-handed), which aims to stand as an objective measure of one's handedness.

The Annett Handedness Questionnaire [30] (AHQ), developed by Marian Annett , also in 1970, shares many of the same items of inquiry with the EHI (6 of 10 items on the shorter EHI edition are present in the AHQ), but uses a very different methodology for producing a quantitative handedness evaluation. Annett relies on associative analysis to classify the 12 items of inquiry on her questionnaire into two even groups. The primary group contains items which act as greater indicators of one's handedness. Secondary actions have less of a correlative relationship with one's handedness. When answering the AHQ, participants may only select one of three ratings for the item in question, as opposed to the EHI, which contains a 5-point scale. The associative analysis method for the AHQ was adapted from the ecological studies of Williams and Lambert in the 1960's [33]. Once the resultant scores had been calculated, Annett devised an 8-point classification scale to assist in interpreting the AHQ's metrics.

While handedness questionnaires provided researchers with a quick and easy tool for quantitatively assessing handedness, evaluations of these methods demonstrated that they produced poor assessments [34]. Choosing tasks to inquire about is difficult partially due to cultural influences. While inquiring about which hand a person writes with seems like a simple indication of hand-preference, those living in East Asia for instance, [35] are likely to experience cultural pressure to use the right-hand over the left. Questionnaires task the researcher with issuing a level of importance to each task when assessing the metrics of handedness' effects. Other issues have arisen with the reliability of re-testing an individual, as left-handed individuals tend to change their answers more often than their dextral counterparts [1].

2.2.2 Performance-Based Tasks

Issues inherent with questionnaire classification have given rise to performance-based classification methods. These tests are more time consuming than the questionnaires, and require controlled conditions and detailed analyses. Performance-based tests still hold the advantage because they do not rely on the participant's recollection or personal opinion on which hand they prefer; the behaviour of the participant can be observed [34].

There have been many performance-based tasks developed over the years. These newer methods seek to measure not only hand preference, but hand skill as well. Some of these performance-based measurement methods range from a collection of tasks, such as the *Wathand Box Test* (WBT) [36], to a simple tapping task [37].

The Wathand Box Test

In the case of WBT, the participant simply performs a series of tasks which would normally be found on a questionnaire. Such tasks include the tossing of a ball, and using a (toy) hammer. As the participant performs each of the various tasks, the researchers simply mark which hand was used for each task. A laterality quotient is then produced by subtracting the number of times the left-hand is used from the number of times the right-hand used, and dividing by the number of tasks performed.

Pegboard Tasks

Two other prominent tasks which involve the manipulation of physical objects are the *Annett Pegboard Task* (APT) [38] and the *Grooved Pegboard Task* (GPT) [39]. The APT requires participants to move pegs from one set of holes to another while being timed. In addition, the APT is performed uni-manualy and requires alternating performances of each hand. The hand which begins the study is randomized. After three trials, the completion times are averaged to produce the LQ. The APT shares many similarities with the GPT, developed by Lafayette Instruments. The GPT differs in that the pegs are irregular in shape and only fit into the required hole from a specific position. Furthermore, the GPT requires participants to grab the pegs from a box and find the appropriate hole for one phase, and then to retrieve them and place them back into the box for the second phase.

Similar to the APT, the times for each hand are averaged (the GPT requires two rounds per hand) to produce the LQ.

Tapping Tasks

Measuring the speed and regularity of finger tapping has also been quite useful and popular in performance-based laterality testing. Although the specifics may vary from study to study, tapping-based performance testing looks for the timing of inter-onset-intervals (IOI), and how they change over time. The lengthening of IOIs and irregularity in tapping is often a sign of fatigue, and signals the weaker hand.

Tapping has also been used to observe the effects of handedness in phase wandering [40], and the effects of attention on handedness performance [41]. Furthermore, other tapping-based studies have shown that the non-preferred hand performs better when it is fully automated [42], suggesting that when the attention is shifted away from the preferred-hand, the performance quality of each hand is reduced. Recent findings have suggested that although the preferred hand generally receives most of the attention when a task's difficulty is increased, the overall speed of the given action can have an overriding effect. Thus, an individual will move their attention towards the hand that performs the faster task. Regarding the timing of events in a bi-manual task, there is evidence that tapping with the non-preferred hand produces more variable timing [37]. Other studies have revealed a possible link between the starting hand in a tapping task and language. Between a group of normal and dyslexic participants, the normal group consistently started tapping tasks with their preferred-hand, while the dyslexic group began using either hand with equal frequency [43].

2.2.3 Handedness in Music

When considering handedness research, the wide-ranging influence of its effects have given way to a large number of studies in many different disciplines. Due to the intrinsic nature of the hands in instrumental performance, music has been an area of intense focus. In the literature, it is generally concluded that an individual's handedness does not provide one with any inherent advantages or disadvantages with regards to musical ability [44]. Further studies have investigated the influence of handedness in reaction times of musicians [45], showing that the musicians have more balanced bilateral attentiveness than non-musicians.

The previously mentioned studies involving tapping included a focus on the differences between expert drummers and non-drummers, displaying the advanced movement strategies used by percussionists [21] [22].

2.3 Technical Approaches to Handedness and Symmetry

The notion of symmetry in percussion is an inherent yet rarely addressed issue in learning, teaching, and performing. Previous research [21] [22] has shown that musical experience and practice reduces the asymmetry between maximum tapping frequencies between the left and right-hands. Non-experienced performers tend to display a wider variance between maximum tapping, as well as phase-wandering (inconsistent phase-transitions). Experienced drummers often display no phase-wandering. In addition, previous findings suggest that while hand preference can remain the same, asymmetry between sides can be reduced over time with practice [22]. Yet, while there is strong evidence for the reduction of asymmetry, it does not seem possible to completely overcome the effects of handedness.

2.3.1 A Percussionist's Perspective of Symmetry

The concept of asymmetry is integral to the interactions that take place between percussionists and their instruments, and can be observed in a variety of ways. Once example can be seen in four-mallet performance on the marimba, where the left-hand is often required to work with a physically larger range due to the increased size of the bars in the lower register [46]. The asymmetrical shape of a modern 5-octave marimba can be seen in figure 2.1. Mallet instruments, unlike their distant cousin the piano, require the performer to physically strike the sounding body. Whereas a piano-key acts as a trigger, sending the hammer to strike the string inside the piano, a marimba performer must strike the key itself. The lower the pitch the physically larger the bar must be. Therefore, the right-hand is made to work with physically smaller intervals, requiring very different movements and fine-motor skills.

These effects are exaggerated when it comes to multi-percussion performance, where collections of instruments have the potential to demand awkward leaps and close-quartered movement from the percussionist. As an example, in Brian Ferneyhough's *Bone Alphabet*, the performer is asked to gather a collection of instruments from specified families, rather than indicating the precise instrument itself [47]. In this case, the same piece can be

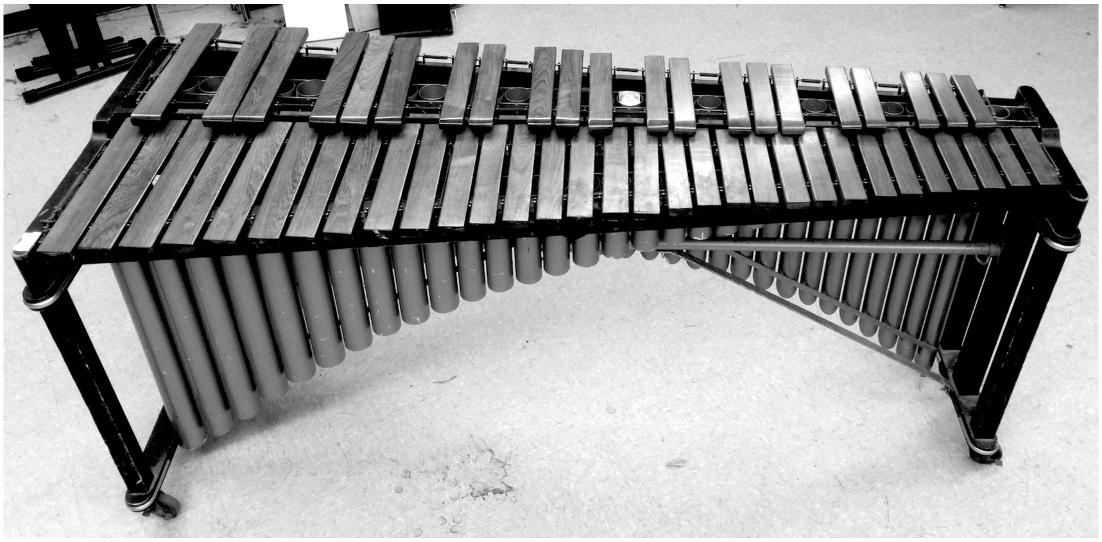


Fig. 2.1 An example of a modern 5-octave marimba. Note the wide variety of bar sizes, and how different the left- and right-sides are. This greatly influences the functional roles of the hands when performing.

performed by the same performer, but with a completely different physical set-up each time. By these standards, percussionists are accustomed to adapting to new space.

Symmetry can be easily seen in the circular playing surface of most membrane instruments. Although the sound and feel is dependent upon the tuning of the lugs, in ideal conditions, a tom-tom can be approached from any side with the same technique by the performer when using matched grip (figure 2.3a).

2.3.2 Evenness in Percussive Pedagogy

Whether a performer is a novice or a professional, the snare drum is a staple instrument of percussion pedagogical practices, and an area of intense focus when developing technique.

In the beginning phase of learning percussion, many teachers instruct students to begin with simple, single strokes on the snare drum at a comfortable pace to gain an understanding of the physics of the drum. Beginning objectives often include learning how the stick rebounds from the drum-head, how the fingers and wrist respond to the bounce in order to gain control, and how the arms must react so that a new stroke can be initiated. All of these actions happen without much conscious thought, yet are crucial to developing a healthy, proper technique. When considering the concept of symmetry in the beginning phases of

(a) Concert Snare-Drum

(b) Timpani

Fig. 2.2 These are two examples of symmetrical percussion instruments. The playing surface is ideally perfectly circular, and provides an equal playing surface for each hand.

learning, many method books and teachers describe the desire for a player to produce *even* strokes with an *even tone*, with little further description [48] [49]. *Evenness* is often used as a catch-all word, meant to address both the sound and performance technique of a player.

While symmetry is not always directly addressed in method books and private lessons, players are taught to look for discrepancies between the left- and right-side. A lack of evenness between the two halves can result in a disproportionate use of the arms, as well as acts of compensation to balance the sound. This can result in pronged tension and injury, which is why evenness is crucial for developing a sustainable technique.

2.4 Preliminary Studies on Handedness in Percussion

Although the effects of handedness are well documented in many fields of study, and have been the subject of close academic scrutiny for decades, there have been no studies directly the gestural effects of handedness in percussion performance. Furthermore, studies on musical gesture have not taken handedness into account.

Given the unknown nature of handedness in a percussion performance context, two preliminary studies were conducted on snare-drum and timpani with the general goal of observing how handedness might affect one's gesture. Before the findings of each preliminary study are presented, there will be a short review of modern snare-drum and timpani technical grips.

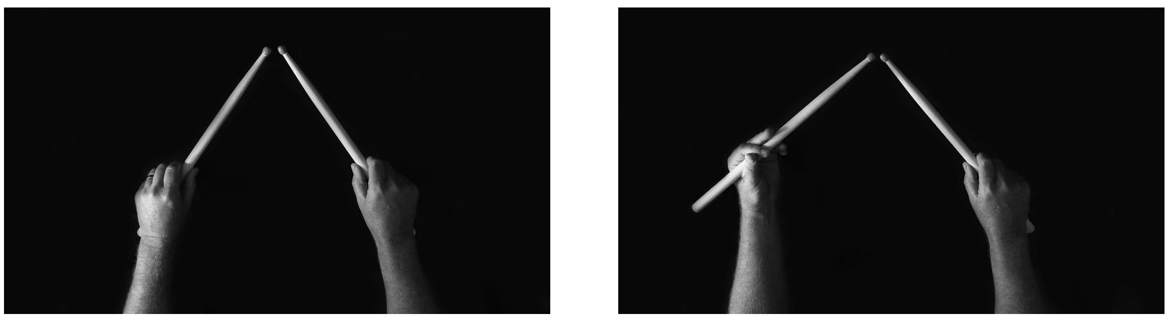
2.4.1 Snare-Drum

In this first example, which discusses the possible effects of handedness in percussion performance, stems from observations made by the author of his own snare drum playing. Observations from this trial spurred interest in the handedness phenomenon, which lead to the review of motion capture data presented in chapters 3 and 4. The motion capture session was conducted as a preliminary experimental trial, seeking to observe the possible effects of phase-transition [40] , in a simple snare drum exercise. Phase-transition in this sense refers to an abrupt shift in gait similar in nature to a walking-running transition. The study was modelled after research conducted by Rasamimanana in 2009 [24], in which a violinist and violist were asked to perform an *accelerando* and *deccelerando* while having their movements recorded by a motion capture system. In this study, the notion of *gestural continuity* was presented, which can be used to explain the subtle variations of performance gestures that occur when moving from one technique to the next (*e.g. detaché* and *martelé*).

The preliminary study performed by the author further investigates the concepts of gestural continuity and phase-transition, with a slightly different task. Instead of performing an *accelerando* and *deccelerando* freely in time, the participant (the author) performed a *crescendo* and *decrescendo* using a fixed tempo. In percussion, stroke speed is integral to the performance of both dynamics and tempo. To perform a *crescendo* and *decrescendo*, the percussionist must increase and decrease stick speed accordingly. The addition of a fixed meter forces the performer to exert more control over the stick, so that the desired change in dynamic levels fall within the specified time signature. When performing only an *accelerando* and *decelerando*, the rebound feeds more naturally into the percussionist's movement since there is no need to evenly space each stroke. Therefore, the performance of a smooth and aesthetically desirable change in dynamics in a fixed tempo requires a comfortable phase-transition from the performer. This study is focused on the percussionist's posture pre- and post- phase-transition, and displays how handedness can potentially alter the performance technique.

Snare-Drum Technique

A basic fact within the world of musical performance is that one's technical approach is hugely important. Pertaining to both short- and long-term consequences, performance technique effects playing quality, endurance, and overall musical ability. The enormous diversity of percussion instruments across all cultures has produced an equally large number of technical grips and postures [50]. Technical approaches to the snare-drum today fall into one of two categories: traditional- or matched-grip.



(a) Matched-Grip (b) Traditional-Grip

Fig. 2.3 Figure 2.3a is an example of Matched-Grip. This is a symmetrical grip which requires the same action from each hand to perform. Matched-Grip is the more popular choice for performers today. Figure 2.3b is an example of Traditional-Grip. Note how the left-hand is turned over while the right-hand maintains the same position found in Matched-Grip. Image credit *Jazeen Hollings* under the terms of *CC-by-3.0*.

The traditional-grip has its roots in military history, as the drummers in armies typically marched with the snare-drum slung over their shoulders. This caused the drum-head to have a slight inclination. Because the playing surface was not evenly flat, the player had to rotate the wrist of the left-hand over, in order to play comfortably.

Traditional playing technique, proliferated by military drumming, eventually became the de-facto style in the concert hall. A view which represents the standard traditional grip can be seen in figure 2.3b. As the snare-drum became more popular in orchestral music, players continued to rely on traditional snare-drum grip well into the 1950's. It has only been within the passed 20-30 years that traditional grip was has fallen out of favour. One possibility for its decline in popularity could be related to the inefficient use of muscles in the arm. It has been shown that traditional grip requires a significantly greater number of muscles to properly execute a stroke [48].

Matched grip is now the most common playing technique for percussionists today. The symmetrical grip gives the performer increased flexibility, which is often necessary when performing contemporary music. On snare-drum, multi-percussion, and timpani pieces, variants of matched grip can be used with relative ease.

As seen in figure 2.3a, matched grip is very similar to German grip on the timpani (figure 2.7). In this case, both the hands grip the stick with the wrists facing parallel to the ground. Slight alterations can be made to suit a particular individual or instrument as well.

Data Acquisition and Analysis

This experimental trial consisted of a simple 5-measure exercise of straight sixteenth notes performed by the author, with a crescendo from pianissimo to fortissimo and back. The tempo for the exercise was held at 120 BPM, with a total length of 10 seconds. To record the movement of the performer, the exercise was conducted in the Performance and Recording Lab at Center for Interdisciplinary Research in Music, Media, and Technology (CIRMMT) using the Qualisys Motion Capture System. The movement was recorded with a sample rate of 210Hz using 11 Qualisys Oqus 400 cameras. A total of 26 markers were placed on the performer, with the markers on the arms and wrist corresponding to the Vicon Plug-in-Gait diagram [6].

Upon reviewing the data from the exercise, differences between the left- and right-sides of the body were observed, even before any phase-transition took place. In figure 2.4, differences in the height of the left and right wrists can be seen immediately. Furthermore, the effects of phase-transitions were different for each hand. Before the arrival at *fortissimo*, the left wrist began to push down and then rise at a steeper rate than the right-hand. It is also apparent that, despite the lack of an indication of stick ordering in exercise, the right-hand always struck first. Given that the performer is right-handed, it could be hypothesized that the right-hand began each exercise because of the preference given to the dominant hand when performing temporal tasks [42].

Percussionists are often trained to observe their technique in a mirror, to ensure that each limb produces a similar stroke. A lack of focus on the left-hand side could possibly be explained by preference in attention given to the dominant right-hand side, resulting in a less disciplined and technically unrefined left side gesture profile. In general, the right-

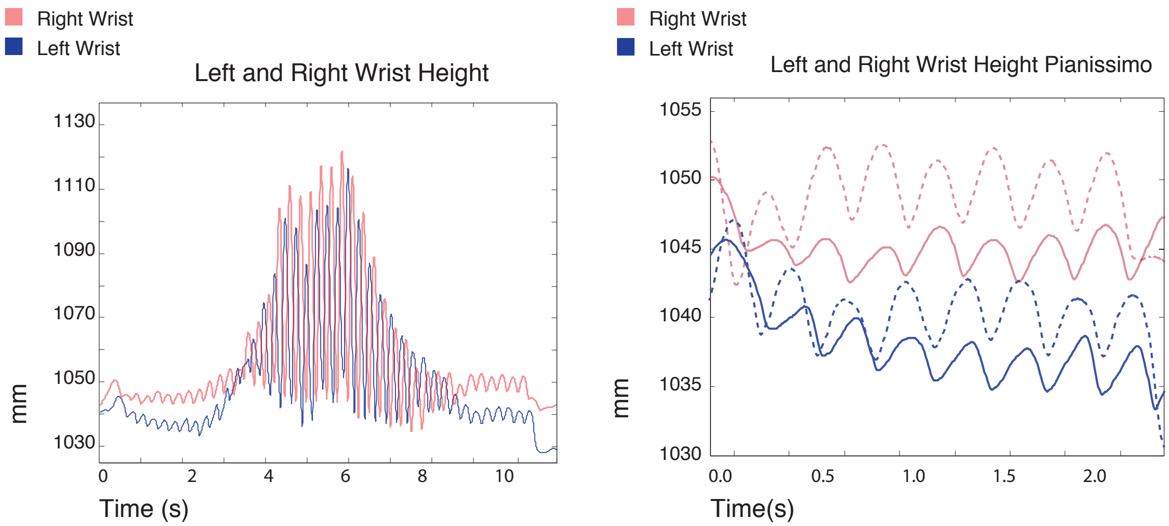


Fig. 2.4 Wrist height for the duration of the entire exercise and a comparison between *pianissimo* segments for each hand pre and post phase-transition. The dashed line represents the second pass of the *pianissimo* passage after two phase-transitions.

hand side of the body performed a more controlled and technically efficient execution of the performance exercise. It can also be noted that the phase-transition had a similar effect on each half of the body when comparing the first and last measures of the exercise, which can be seen in the right side of figure 2.4. Upon exiting the last phase-transition, each hand was performing the same *pianissimo* dynamic marking at a greater height compared to the beginning of the exercise.

2.4.2 Timpani

The next two examples borrow data from [51], which proposed novel analysis, modelling, and synthesis strategies for percussion performance. These examples display the movement of a right-handed professional timpanist and a left-handed undergraduate percussion student. In each exercise, the performer was asked to play *legato* timpani strokes, with a steady tempo of approximately 67 bpm and a *mezzoforte* dynamic level. These exercises are useful because they display the motion of a simple stroke without any required change in tempo or dynamics, which can exaggerate differences in the left and right-hands. Therefore, an accurate sense of the natural and relaxed striking gesture can be observed.

Timpani Technique

Contemporary timpani technique in most of Western Europe and North America has typically been dominated by three main playing styles: German grip, French Grip, and American grip [48] [52].

German grip, which can be seen in figure 2.7, closely resembles the matched grip used for snare drum performance. The wrists are generally held flat across the drum-head while a stroke is executed. To initiate a stroke, a gesture similar to that of a *wave* is performed with the arms. Because German grip is dependent on flexing the wrist up-and-down, German grip typically leaves the mallet-head in contact with the drum-head for a longer time than that of the French [52]. In most cases, this grip is considered utilitarian due to it's similarity to snare-drum grip. German grip is generally thought of as an introductory grip [52] [48].

French grip departs from German and most other grip styles due to the inclination of the wrist. In French grip (figure 2.5), the hands are rotated so that the thumbs are pointing straight up. The mechanics of a stroke using this grip rely on rotating the wrists downward when performing a stroke. The fingers underneath the stick provide subtle control and give the performer a very delicate touch. French grip provides the performer with more flexibility due to the fact that the mallet can be retracted from the drum-head very quickly [48] [52]. This grip is very popular with professional timpanists [49], but very difficult and usually impractical to employ in a multi-percussion context.

American grip is a more recent development in timpani technical grips. While in French grip, the wrists are perpendicular to the ground, and in German grip, the wrists are parallel, American grip floats between the two. The mechanics of a stroke can contain any variation of traits found in the German or French grips. American grip, seen in figure 2.6, can be considered as an individual's personal hybrid of German and French grips.

Data Acquisition and Analysis

The motion data was captured using the Vicon Plug-in-Gait protocol and a Vicon infra-red motion tracking system in the Input Devices and Musical Interaction Laboratory at McGill University. The complete details on the motion capture protocol used to collect this data can be found in [51].

In figure 2.8, the tracing of each stroke with regards to distance and height (*i.e.* the y and z dimensions, where y is the sagittal distance in front of the performer and z is the

Fig. 2.5 This is an example of French timpani grip. Note how the thumb is facing upward.

Fig. 2.6 This is an example of American timpani grip. Note how the thumb and wrist lie slightly between the German and French grips.

Fig. 2.7 This is an example of German timpani grip. Note how the wrists are generally flat, similar to that of a matched snare-drum grip.

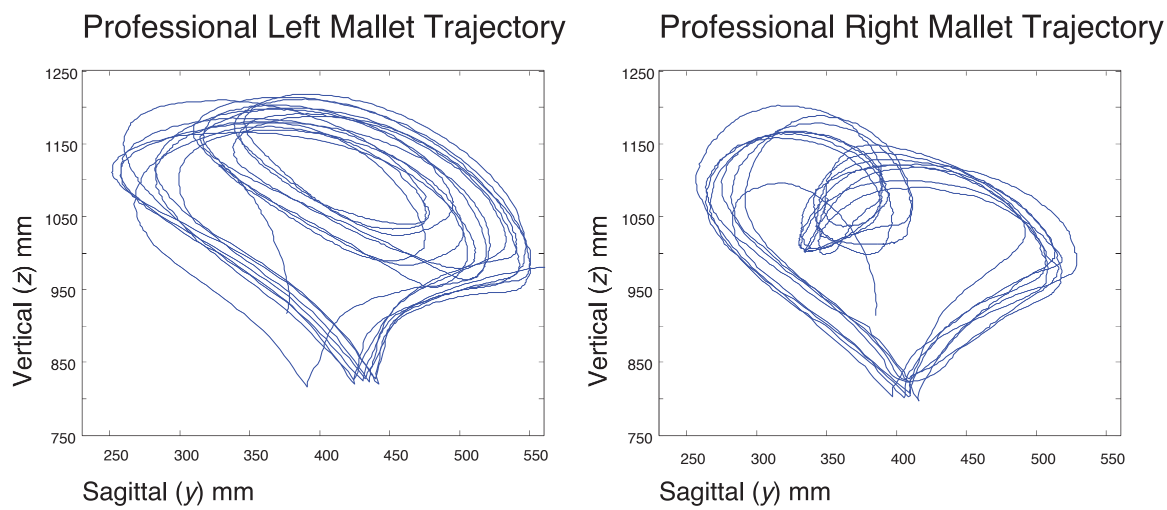


Fig. 2.8 The mallet trajectory for the duration of the entire exercise.

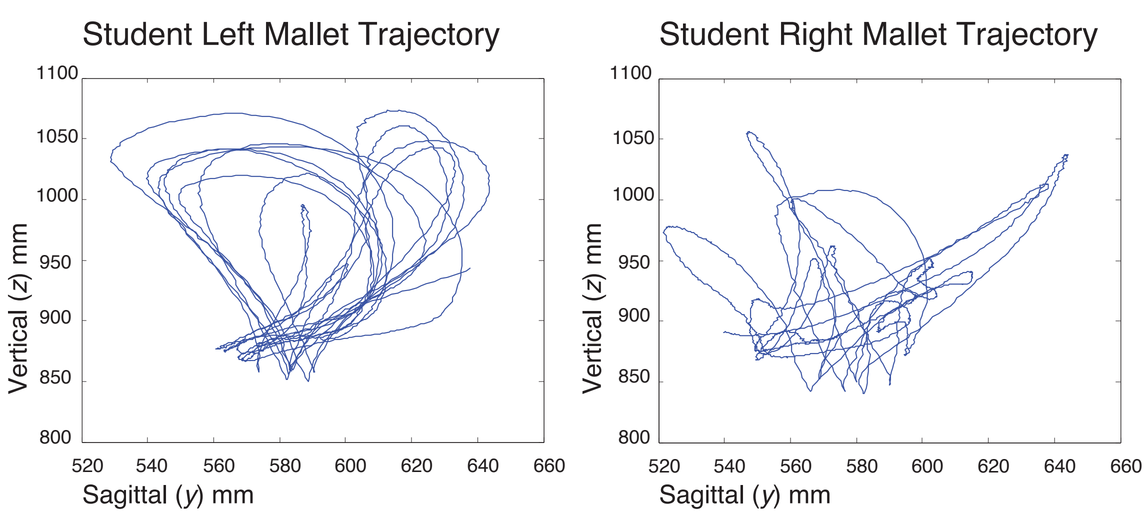


Fig. 2.9 Mallet trajectory for the duration of the entire exercise.

height) can be observed. This graphical representation displays the gestural profile of the performer, where differences between the left and right-hands can be clearly seen. Long and expressive movements characterize the trajectory of the professional's gesture as each stroke is executed with a high level of precision. Major differences between the left and right-hands can be observed in the upper half of each stroke. This area corresponds to an ancillary gesture which demonstrates qualities of expression. After each stroke, the right-handed professional timpanist lightly preps the mallet as if conducting with a baton, while the other mallet strikes the membrane. This motion is greatly exaggerated in the left-hand as the mid-stroke *loop* is much larger. In comparison, the right-hand experiences a much smaller range of movement. One such consequence of the larger movement found in the left-hand can be observed in figure 2.10, which was calculated using the *mirpeaks* function from the MIR Tool Box [53]. This graphic displays the peaks in recorded audio from the exercise. Given that each performer began with their dominant hand (undergraduate is left-handed and the professional is right-handed), a dissimilarity in dynamics between each hand can be found. Here, the left-hand of the professional consistently plays a quieter strike. The student (a left-handed player), seems to perform inconsistently regarding dynamics.

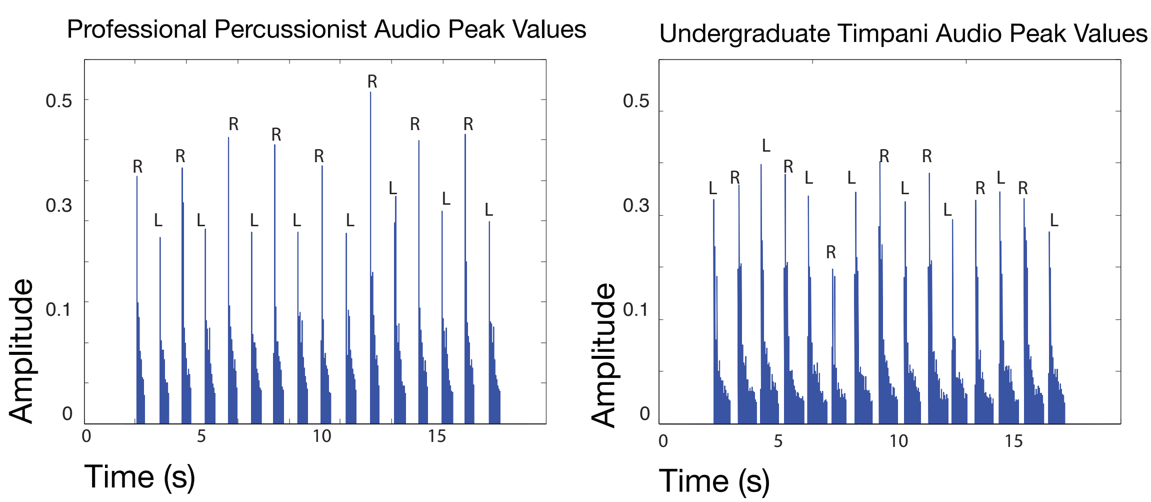


Fig. 2.10 Peak values for the professional and undergraduate timpanists.

While there are slight, yet obvious differences between the left and right-hand sides in the professionals gestural profile, asymmetry is certainly magnified in the student example. Here, a left-handed undergraduate student performs the same performance task as the professional. By observing the results in figure 2.9, the effects of handedness and lack of experience is apparent. While the undergraduate's left-hand displays larger and more elliptical strokes similar to that found in the professional, the right-hand moves in an inconsistent manner. Each stroke is approached from a different angle and mid-stroke movement is often erratic and unpredictable. This can be explained by excess rigidity in the non-dominant hand, resulting in a lack of control when attempting to influence the rebound trajectory. Regarding the technical grips of each player, both appeared to utilize a personalized version containing a combination of traits from the three predominant techniques (German, American, and French). The professional employed a grip which was French in manner, while the undergraduate performed with a more German-like grip. The difference in grip could account for the maximum strike height between each performer, but not the differences in the left- and right-hand sides. Since German grip bends the wrists up and down, this can somewhat limit the maximum stroke height. Because French grip relies on the rotation of the wrists, the trajectory of the mallet-head tends to sit at the sides of the body, allowing for a greater range of motion. A horizontal wrist lifts towards the shoulders, somewhat limiting vertical motion.

An analysis of the peak data from the audio in this example also demonstrates a lack of comfortable control in dynamics as well. Through a simple visual analysis, handedness exerts an influence in determining the mallet trajectory and overall gestural profile of each timpanist, regardless of experience.

2.5 Conclusion

As discussed in this chapter, the notion of symmetry and handedness in percussion performance is a complicated issue, tying together many different perspectives. While reliable attempts to quantify handedness have been difficult pinpoint (section 2.2), understanding that the lateral differences of the body can have a strong influence over how we move is easy to see (section 2.4).

The physiological tendencies of a performer's technique can differ greatly from player to player. Compromises are necessary and a natural part of learning how to play. For this reason, percussion pedagogy today often strives for *awareness oriented* learning; goal-oriented learning is not as constructive and often unattainable [48]. An individual performer's technique will always display aspects of asymmetry, resulting in a unique gestural profile.

With this in mind, the following chapters seek to reveal what factors affect the symmetry of the hands in percussion performance, especially in relation to their gestural movement (chapter 3) and how they react to metric function in musical notation (chapter 4).

Chapter 3

The Effects of Handedness on a Neutral Task

This chapter presents the results of the neutral task phase of the handedness in percussion experiment. The overall experiment consisted of two parts: 1) A Neutral Task, and 2) Sight-Reading an original score.

In each of the two tasks, no indication of technical approach was present. The fact that the neutral task of the experimentation was labelled as *neutral* does not suggest that the other task (*i.e.* Sight-Reading) was inherently bias towards one of the hands. The neutral task was designed to be unbiased with regards to the roles of the hands in musical function. Musical function in this case refers to rhythm, dynamics, and notes. As will be stated in chapter 4, musical function can have an interesting effect on the hands. While the sight-reading task required the performer to either issue a response to or invent elements of musical notation, the neutral task was developed as the control. With a task that contained no written notation, dynamics, or note changes, observations on the participant's performance gestures could be made with as little interference as possible. The following sections discuss the development of the neutral task, the experimental methodology, results, and discussion.

3.1 Neutral Task Development

The neutral task was created with the goal of observing the participant's movement with little to no interference from modifying musical elements. One of the key inspirations for the design of this simple task comes directly from the percussion literature. First written by George Lawrence Stone in 1935, *Stick Control for the Snare Drummer* is a ubiquitous method book for percussion performers regardless of experience [54]. In *Stick Control*, exercises ranging from simple quarter-note pulses to advanced poly-meter rhythms provide excellent diagnostic tools for performers. Although the book was written with the snare-drum in mind, the exercises presented there are easily transferable to other percussion instruments, including timpani and mallet instruments.

These exercises exist with multiple sticking choices so that the performer can identify where his or her weaknesses lie. For example, performing one pattern when starting with the right-hand can be much more difficult when the stick ordering is reversed. This is a subtle nod to the wide-spread influence of handedness in percussion performance.

Because of their simplicity and design with regards to identifying the effects of handedness, the exercises from *Stick Control* (*i.e.* warm-ups) were determined to be an excellent starting ground for the design of this neutral task. The book begins with simple quarter-note exercises, which instruct the player simply strike with alternating hands at a consistent tempo. While the book offers many stick ordering suggestions, the neutral task in this experiment did not contain any sticking suggestions. Participants in the experiment were free to start with whichever hand they wished.

This exercise, with are performed before serious practicing, are analogous to the routines of athletes (*e.x.* distance runners, weightlifters), where slow jogging and trotting are useful in decreasing body tension, while at the same time promoting good form and technique [55]. The goal of the neutral task was to allow the participants to perform as freely as possible.

3.1.1 Relation to Warm-ups

Due to the high degree of physicality in percussion performance, injury can result from a lack of proper warm-up. Tension and strength are frequently addressed in percussion performance method books. The goal of any percussive stroke is to perform it in a relaxed yet controlled fashion. Proper technique promotes a fluid motion, while maximizing control at the necessary moments. For example, tightening one's grip around the stick in an attempt to gain greater control can lead to rigidity, making it more difficult for the percussionist to transition between techniques. Careful changes in tension and posture can help a percussionist transition smoothly between dynamic levels and achieve virtuosity. Although nerves play into this to an extent, it is nevertheless important for each player to develop a pre-performance routine.

The first task for this experiment was developed to reflect the most basic of warm-ups. Each participant was asked to perform a series of alternating strokes at 80 bpm, with no indication of articulation or drum head position. Furthermore, the exercise did not call for any tempo changes. A general dynamic suggestion of mezzo-forte was indicated to each performer in order to prevent a wide variety of approaches to stroke trajectory. Mezzo-forte implies a level of control and steadiness commonly understood by performers, and reflects the average dynamic level called for in most percussive method books.

3.1.2 Neutrality and Symmetry

This task calls for symmetrically bi-manual efforts from the hands, and does not require specific techniques or articulations. Therefore it has been labelled the as the *neutral* task. The main purpose for the neutral task in the context of this experiment was to evaluate the participants' stroke trajectories outside the context of musical performance. In the larger scheme of this experiment, the neutral task represents the control. Here, the performance actions of the participant are reduced to their barest essentials. By asking each participant to perform a symmetrical bi-manual task, the effects of handedness can be observed with minimal interference from the many possible cultural influences found in percussion performance.

Symmetry can be seen as a key component of the neutral task's unbiased approach to handedness. Given the symmetrical shape of the timpani, the physical requirements to produce sound from the instrument are the same for each half of the body.

3.2 Neutral Task Methodology

The neutral task in this experiment was administered in the Motion Capture Laboratory of CIRMMT. Using the same pair of carbon-fibre David Herbert DH2 timpani mallets [56], participants were counted in for the first 4 beats of the 80 bpm exercise to ensure a steady and comfortable entrance. The total exercise length lasted for 30 seconds.

3.2.1 The Participants

The participants for the handedness exercise were selected on a volunteer basis and were each compensated $40 CAD for their time, regardless of whether or not they were able to complete the experiment. Overall, 9 participants were selected for the entire handedness experiment (the neutral task and sight-reading phases). This portion of the study selected data from 6 of the 9 participants, which consisted of 2 females and 4 males. The 3 other participants which are not included in this study were left out due to issues with the motion capture data (Participants G, H, and I). Every participant (Participants A-I) are featured in chapter 4. Detailed information on the participants analysed in the neutral task can be found in table 3.1. The average age of the participants was 23.83 years, with an averaged 12 years of percussion instruction, and 7.83 years of timpani instruction. Overall, this group of participants can be considered quite advanced, with many years of performance experience.

The participants were instructed to employ their preferred technical grip, and to not place an emphasis on rigorous time-keeping. Percussionists have the habit of treating the most simple tasks with a high degree of seriousness when regarding the consistency of their time-keeping. In an experimental setting, it is possible that such an emphasis on keeping a steady tempo could introduce unwanted changes to the performers' technique (*i.e.* increased tension and rigidity). The ultimate goal was that each participant perform in a relaxed and comfortable manner.

Following the experiment, the participants were invited to provide brief evaluations of their playing performance quality throughout the entire experimental process. This step was added to ensure that any recorded results were the product of each performer's natural playing style. No performed indicated any discomfort caused by the motion capture markers, nor were any of the participants injured at the time of the experiment.

This experiment was approved via a *REB-II* license by for McGill Ethics Committee to ensure the safety and comfort of the participating persons. The document can be seen in full in appendix B, figure B.3.

3.2.2 Performance Space and Equipment Protocol

The motion capture facility contained a system of 8 *Qualisys Oqus 400* motion cameras recording at 200 Hz. These cameras emit and receive infra-red light which is reflected off

Table 3.1: This table presents the 6 participants who were analysed for the neutral task phase of the handedness experimentation. This information was provided by the individual participant and was collected prior to the experiment. Am, Ger, and Fra correspond to American, German, and French grips, respectively. MM1 and MM2 refer to the completion of the first and second year towards a Masters of Music degree. DMA refers to the completion of a Doctorate in the Musical Arts.

Participant	A	B	C	D	E	F
Age	29	23	23	22	21	25
Sex	Male	Male	Male	Female	Female	Male
Hand Preference	Left	Left	Right	Right	Right	Right
Years of Instruction	17	6	13	13	12	11
Instruction on Timpani	14	6	5	4	9	9
Technique	Ger/Fra	Ger	Fra	Am/Ger	Am/Fra	Am/Fra
Degree Status	DMA	MM2	MM2	MM1	MM1	MM2
Current Status	Professional	Student	Student	Student	Student	Student

of passive motion capture markers. These markers are covered in a reflective material, and were affixed to each participant using a light, temporary adhesive.

To analyze the motion capture data, the *Qualisys Track Manager* (QTM) software was used. The motion-capture markers were all labelled and placed according to the Vicon Plug-in-Gait [6] scheme. Once the markers were correctly identified, gaps in the marker trajectory less than 5 frames were individually inspected and filled using the QTM software. After the motion capture sessions were prepared, they were exported through QTM [19] as a *.mat* (MatLab) file. Once in MatLab, all of the trajectory plots and measurements were produced using the MoCap ToolBox [7].

In addition to motion capture cameras, a single *Sony PMW-EX3* HD digital camera was used to record video footage at 25 fps for analysis. Furthermore, the video camera recorded audio of each participant's performances at 48 kHz. External microphones were used in place of the camera's default stereo microphone. In this case, two *Neumann KM 140* microphones were used. These are condenser microphones with a cardioid pick-up pattern.

Further auxiliary data was acquired with the *Qualisys USB-2533* analog acquisition board. The auxiliary data in this experiment was acquired from a *Bertec FP-G060-05-PT* force-plate. In the performance space, the participants would stood on the force-plate, which measures center of pressure. This data *was not* analysed in relation to this study.

To ensure that the audio, video, and motion capture data were synchronized, an external time-code generator was used. Acting as the master clock, a *Rosendahl Nanosyncs HD Multi Standard Sync Engine* relayed time-code information to the master motion capture camera, analog acquisition board, and video camera. In figure 3.1 and figure 3.2 the actual and virtual performance spaces can be seen.

A full version of the motion capture protocol devised for this experiment, complete with signal path diagrams, can be seen in appendix A.

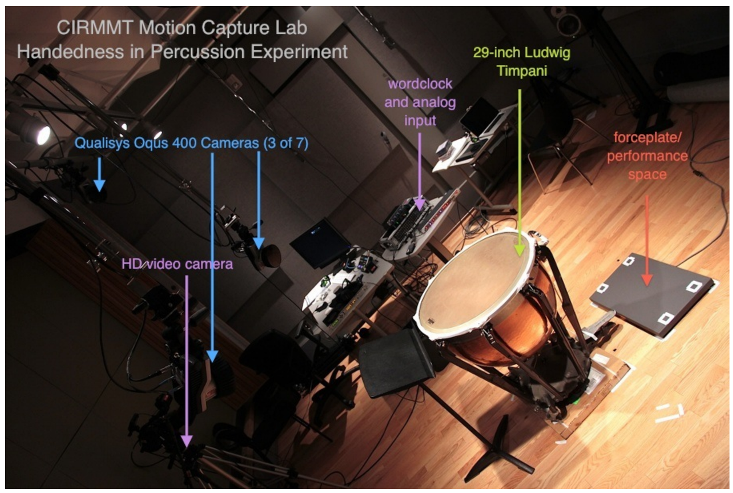


Fig. 3.1 This photo displays the performance space used for the *handedness in percussion* experiment. The photo has been annotated to highlight the equipment used in the protocol, can be found in its entirety in appendix A.

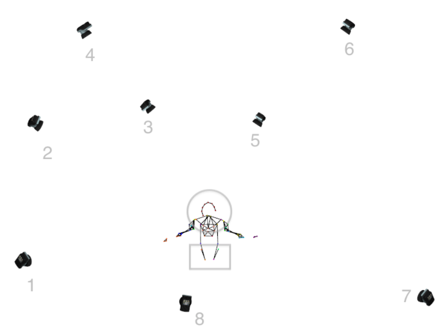


Fig. 3.2 Camera positions relative to the performer can be seen here. In total, 8 Qualisys Oqus 400 motion capture cameras were used. This image was produced with the Qualisys Track Manager software.

Fig. 3.3 This photo displays a screen-shot of a participant performing the neutral task. The perspective of this shot was taken from the HD video camera, whose position can be seen figure 3.1 .

Marker Placement

The motion capture system required the use of passive markers, which were placed on each participant. A total of 65 markers were used. The Vicon Plug-in-Gait Model was used for this study [6]. This marker placement strategy takes advantage of the most stable locations on the body in order to prevent noise in the marker data caused by loose body tissue. In addition, the timpani mallets were fitted with three passive markers and checked to insure they did not interfere with each participant's ability to perform. The virtual model created using the markers can be seen in figure 3.4.

3.2.3 Analysis Methods

The analysis of each participants' gesture was organized into two main parts: 1) Video annotation and 2) Motion Capture evaluation. The initial video annotation phase of the analysis was crucial to observing the entirety of each participant's technical approach. Given that motion capture is an abstraction of the recorded subject, the video annotation phase provided insight into the overall posture and movement of the participants. The video provides a direct connection to the motion capture data, and can be helpful in identifying salient motion capture readings. An example of the video camera's perspective can be seen in figure 3.3.

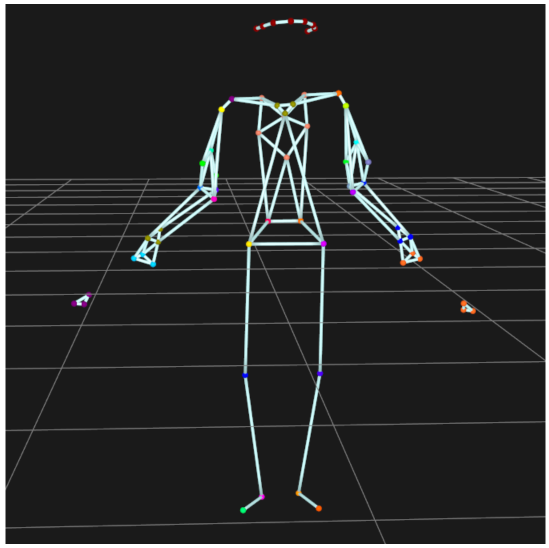


Fig. 3.4 Marker positions on Participant E can be seen here. In total, 65 markers were used. Marker locations and labelling were adapted from the Vicon Plug-in-Gait [6]. This image was produced with the Qualisys Track Manager software.

To discuss the dimensions of each participant's motion, terminology relating to the clinically-oriented anatomical planes is used [57]. The *sagittal*, *transverse*, and *coronal* planes will be referred to when describing important trajectories displayed by the participants. In figure 3.5, the planes can be seen in relation to the human body. In the case that 1 dimension is referred to, X corresponds to motion moving relative to the participant's left- and right-sides, Y corresponds to motion moving towards and away from the participant, and Z corresponds to up-and-down motion (height) relative to the ground.

3.2.4 Hypothesis

Given recent findings relating to the wide differences in gestural movement strategies found among individual performers and the diverse influences of handedness, it was hypothesized that:

- Each of the performers would initialize the neutral task with their preferred-hand due to its rhythmic reliability [42] [37] [43]
- There would be strong differences in stroke trajectory between the hands, especially regarding stroke height and striking area [3] [15]

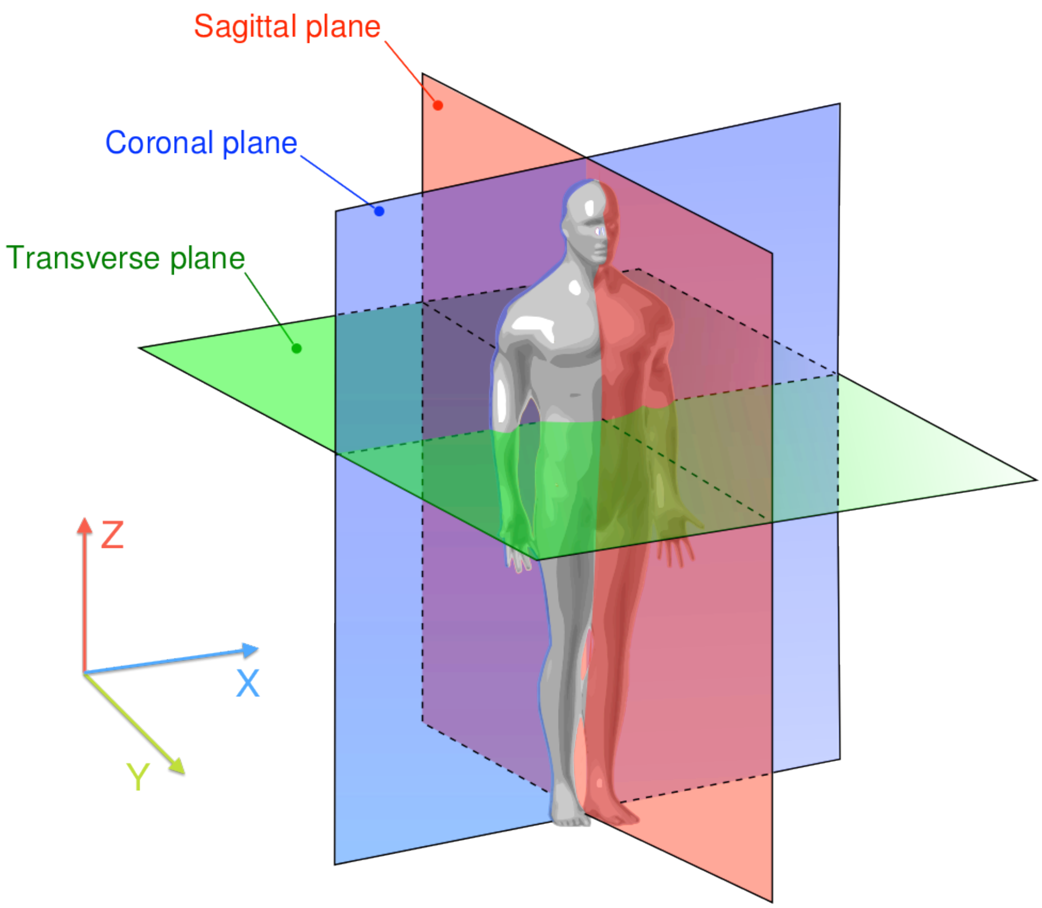


Fig. 3.5 This diagram depicts the anatomically oriented planes used for the analysis portion of this study The sagittal plane incorporates movement corresponding to the Y and Z marker data. The transverse plane incorporates movement corresponding to the X and Y marker data. The coronal plane incorporates movement corresponding to the X and Z marker data. Image credit *Juan Pablo Bouza* under the terms of *CC-by-3.0*.

3.3 Results

In the following analyses, summaries of the video annotation phase will be shown. This will present descriptions regarding generalities of each participant's technical approach (*e.x.* grip style, stick height, posture, expression). Following summaries of the video annotations, salient observations will be reviewed in detail with the assistance of the motion capture data. In-depth observations regarding striking area, and stick height will be presented, along with measurements of the extent of each participant's movement. This will include descriptions of each participant's stick trajectory from the sagittal (z -and y-dimensions) and transverse plane (x- and y-dimensions), strike locations on the drum surface, and standard deviation measurements of the hands. A summary of the calculated results from this experiment can be found in 3.2.

3.3.1 Participant A

The only participant who was not a student at McGill University at the time of the study was Participant A (P-A), who was currently a member of a prestigious percussion ensemble. In addition to having already completed a Doctorate of Musical Arts, P-A had received 17 years of percussion training prior to the study. In addition, P-A had received 14 years of timpani instruction. P-A's cumulative playing experience spanned well past 20 years, given that this participant had already completed a D.M.A. At this point in P-A's career, regular instruction in percussion performance was no longer necessary. Regarding technical approach, P-A uses a functional hybrid of German and French grip. Depending on the repertoire, P-A disclosed that the wrists will rotate towards German grip when necessary. For all intents and purposes, French grip is used when performing traditional timpani music (*i.e.* tasks on timpani without the need or call for extended techniques).

Video Annotation Observations

The video analysis of P-A shows a very confident and relaxed performance of the neutral task. The performance is so relaxed that throughout most of the 30-second task, P-A's eyes were closed.

Stroke Trajectory

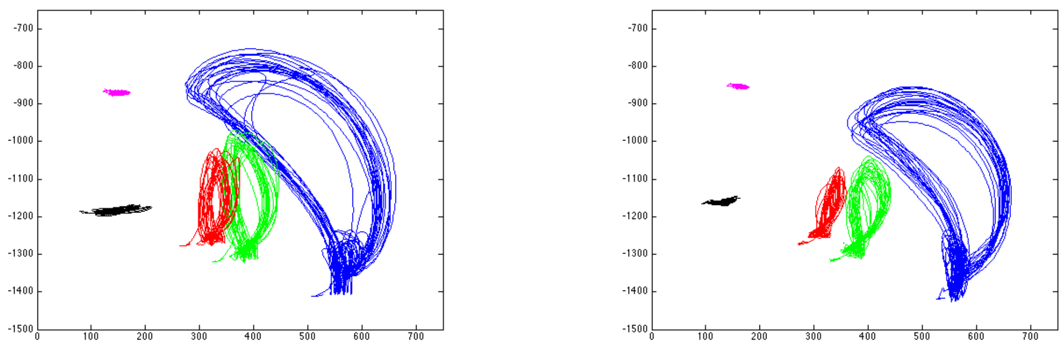
The motion capture data from P-A shows that the overall shape of the performance gesture between the two hands is very similar (figure 3.6). As described in the video analysis segment, the relaxed grip and wrist action of P-A produce a clean pathway for each hand. A sloping crescent form is clearly evident in both hands. Oblong looping trajectories of the wrist, forearm, and elbow trajectories can be seen as well. Since this visualization displays the path of each stroke throughout the 30-second neutral stroke task, there appears to be little deviance from each stroke with regards to trajectory. A relaxed consistency between the hands' individual strokes is evident. Regarding differences between the left- and right-sides, minute differences in the trajectory shape can be seen. The main differences lie in the scale of the gesture itself, which can be seen in figure 3.7a. P-A's maximum stroke height in the left-mallet was measured to be 16.6% (104 mm) higher than the maximum height recorded in the right-mallet. For the average stroke, the left-mallet was 13.3% higher (78.5 mm) than the right-mallet. This ranks P-A second among the participants for the greatest difference between the maximum and average left- and right-sided values.

Stroke Strike Location

As the only professional in the study, it is not surprising to see such a high degree of technical consistency between the hands overall trajectory in the neutral task. As seen in figure 3.7b, while each arm clearly exhibits a different trajectory, the overall consistency displays little variation from one stroke to the next. The angular shape of P-A's transverse stroke profile is the most refined of the 6 participants in the group. When the striking area of P-A is investigated, the left-side occupies a striking area 77.4% larger (71.7 mm^2) than the right. This is the greatest difference in striking area among the 6 participants.

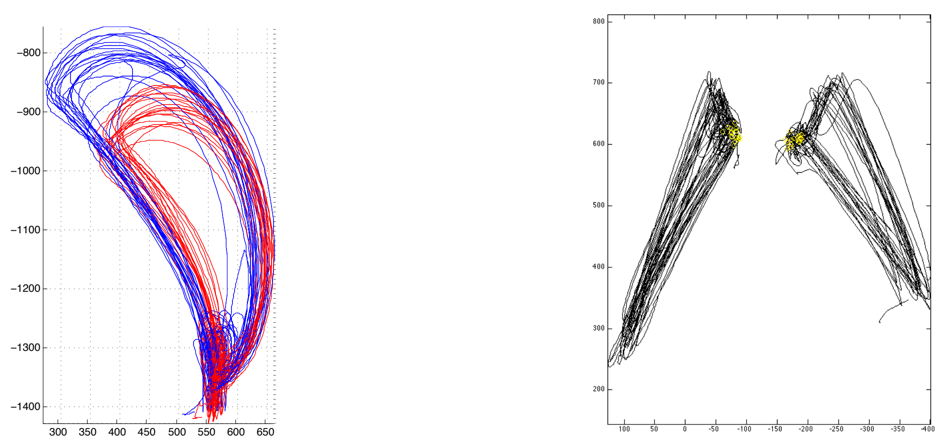
Standard Deviation of the Hands and Body

Strong levels of consistency are clear throughout P-A's neutral task performance (figure 3.18), most likely due to this participant's many years of percussion training and professional experience. One of the most striking observations can be seen when viewing the calculated STD of the L and R hands in the y-dimension (front-to-back). Each hand's extent of movement only differs from the other by 30.4%. Regarding the side-to-side movement, there is a greater extent of movement in the left-hand as well, but by a much larger



(a) Left Arm (b) Right Arm

Fig. 3.6 Participant A's left- and right-arm trajectories. The perspective of the visualization is from the sagittal plane. Units displayed are in millimetres. The following markers are differentiated by color: *Magenta* = Shoulder, *Black* = Elbow, *Red* = Forearm, *Green* = Wrist, and *Blue* = Mallet.



(a) Superimposed Left and Right Mallets

(b) Transverse Trajectory and Strike Points

Fig. 3.7 In figure 3.7a the left and right mallets of Participant A are superimposed. Axes are in millimetres for both figures. In addition, for both figures *Blue* = Left and *Red* = Right. figure 3.7a shows the trajectory from the sagittal plane. Figure 3.7b displays the trajectory of Participant A from the transverse plane where the striking locations can be seen in yellow.

figure (65%). The vertical dimension (z-dimension) of P-A shows yet again a greater extent of motion in the left-hand. This figure differs from the right-hand by 30.4%. Given that trajectory of P-A seems remarkably consistent, including the strike location on the drum, we see that the overall use of the hands differs greatly regarding the height and side-to-side (x-dimension) motion of the hands.

3.3.2 Participant B

To become a graduate student in a competitive performance program requires a significant amount of talent, but also usually many years of commitment and training. Therefore it is quite interesting that Participant B (P-B) who is a self-described left-handed player, listed just 6 years of formal percussion training. Both percussion and timpani instruction had begun at the same time. In most cases, percussionists require the help of a private instructor to meet the rigorous audition demands of universities. It is therefore interesting to see how fewer years of percussive instruction affects the gestural behaviour of each hand. In this study, P-B listed *German* grip as the preferred technical approach to timpani playing. German is generally considered an introductory technique, since less fine movements of the fingers are required [52].

Video Annotation Observations

Throughout the length of the 30 second neutral task, P-B performed with a very powerful stroke from each hand. Both of the hands participated in a *preparatory* timing gesture, where the hand is pulsed up and down briefly before approaching the drum. Given that P-B is left-handed, we can see how the mimicking effect appears but affecting the opposite hand from the right-handed participants. When the left-hand initiates a stroke, it strikes the drum, rebounds, and performs a *timing-prep* gesture. This cycle is repeated for the stroke in the left-hand, while the right-hand performs a slightly different action. When right-hand performs, a stroke is initialized, the mallet rebounds off the drum head, and instead of snapping the hands directly back to their initial state, the right-hand gradually falls into position while the left-hand executes its motion.

Stroke Trajectory

The visualization of the left- and right-arm's trajectories in figure 3.8 reveals that the two sides employ very different movement strategies in the neutral task. The shoulder and elbow trajectories operate similarly, yet the motion of the forearm, wrist, and mallet differ. Here, the left-forearm and wrist are somewhat skewed compared to the right-side. The mallet trajectory of the left-side exhibits a peculiar shape. The upper portion varies greatly compared to the striking area on the drum, where the stroke is more focused. The right-mallet also varies more in the upper portion, but to a lesser degree. The maximum stroke height of P-B is 9.2% higher (52.9 mm) on the right-side. On average, the stroke higher is 8.2% higher (40 mm) on the right-side as well. The recorded differences in maximum and average stroke height between the left- and right-sides of P-B are the 3rd and 4th largest among the 6 participants, respectively.

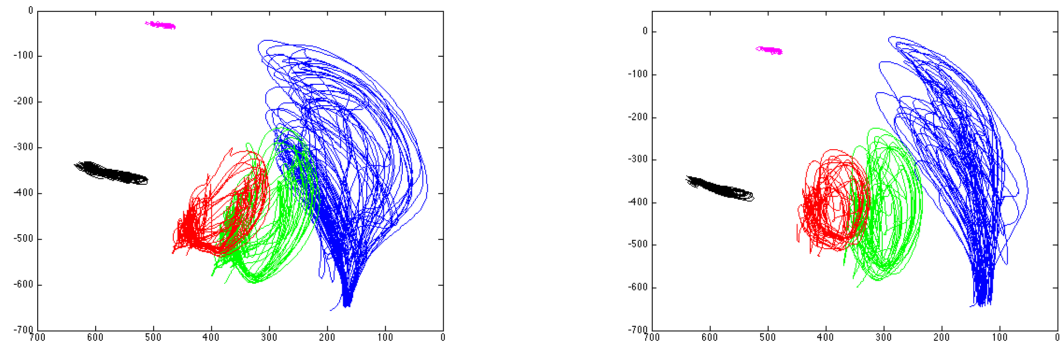
The superimposed mallet trajectories seen in figure 3.9a, show that overall, the left-mallet encompasses a much wider trajectory along the x-axis (the y-dimension in 3D), than the right-mallet. The right-mallet is more linear in nature, and reaches a higher maximum stroke.

Stroke Strike Location

The strike positions on the drum relative to the transverse plane reveal how different the left- and right-hands gestures are (figure 3.9b). While striking locations of the right-hand almost entirely located a the maximum distance from the performer, the left-hand's striking locations are positioned firmly in the center of the striking gesture. Furthermore, the left hand's striking positions are located behind those of the left. Regarding the striking areas of the hands, the left-hand occupies the larger space at 33% larger (66 mm^2) than the right. This places P-B with the 4th largest difference in striking area between the left- and right-sides.

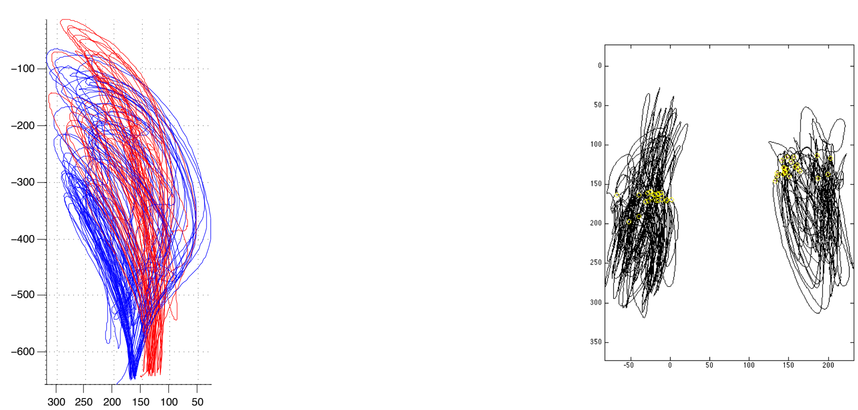
Standard Deviation of the Hands and Body

Vieweing the extent of movement in the z-dimension between the hands using STD (figure 3.18), P-B shows a 16.1% difference. This places the P-B at 3rd out of 6 participants regarding the maximum difference between the hands. The greatest difference in calculated STD between the hands in P-B is observed in the y-dimension (front-to-back) movement.



(a) Left Arm (b) Right Arm

Fig. 3.8 Participant B's left- and right-arm trajectories. The perspective of the visualization is from the sagittal plane. Units displayed are in millimetres. The following markers are differentiated by color: *Magenta* = Shoulder, *Black* = Elbow, *Red* = Forearm, *Green* = Wrist, and *Blue* = Mallet.



(a) Superimposed Left and Right Mallets (b) Transverse Trajectory and Strike Points

Fig. 3.9 In figure 3.9a the left and right mallets of Participant B are superimposed. Axes are in millimetres for both figures. In addition, for both figures *Blue* = Left and *Red* = Right. Figure 3.9a shows the trajectory from the sagittal plane. Figure 3.9b displays the trajectory of Participant B from the transverse plane where the striking locations can be seen in yellow.

Here, there is a wide discrepancy between the hands, where the right-hand exhibits a 50% greater difference than the left. This suggests that the extent of motion in the right-hand's front-to-back movement is twice the amount seen in the left-hand.

3.3.3 Participant C

The participant pool for this study contained four Masters of Music in Percussion Performance students, including Participant C (P-C) who was among the most senior members of the group. Having studied percussion for 13 years prior to the experiment, P-C is certainly an experienced performer. Interestingly, P-C had only received timpani instruction for the last 5 years. This gave P-C the second largest gap of the participants between having started percussion lessons and receiving timpani lessons (8 years). In addition, P-C stands out as the only participant who indicated their technical grip as distinctly *French*. That is, P-C describes their playing as strictly approaching the drum vertically, without tilting the wrists to the side in an *American* or *German* fashion. Furthermore, P-C is a self-described right-handed individual.

Video Annotation Observations

Like many of the other participants in the neutral study, P-C demonstrates a few slight differences in performing the neutral task. While the hands are nearly identical in form, it appears that the left-hand once again is lifted higher than the right. Upon the initialization of a stroke of the right-hand, the left-hand slightly dips down to mimic the trajectory of the preferred hand. It should be noted however that both hands tend to influence each other in this manner. The left is affected a bit more in this regard. Observed pulsations of each hand while the other performs, seem to be related to timekeeping efforts as expected. When considering the performance strategies of the other participants, the overall size of P-C's performance gesture is quite reserved and nearly symmetrical.

Stroke Trajectory

In the video analysis of P-C, little to no major differences between each hand could be seen, except for a possible difference in stroke maximum height. Referring to table 3.2, the maximum and average stroke distances of P-C are the lowest of the 6 participants. When the mallet heights between the hands are compared, we see that the left-mallet is raised

7.6% higher (23.6 mm) than the right on the maximum stroke, and 6.8% (15.3 mm) higher than the right on average. For the first 15 strokes of the study, the left- and right-mallets shared the same contour, differing by only 10-20 mm. The difference between maximum stroke distance and average stroke distance places P-C 4th and 5th largest among the other participants, respectively.

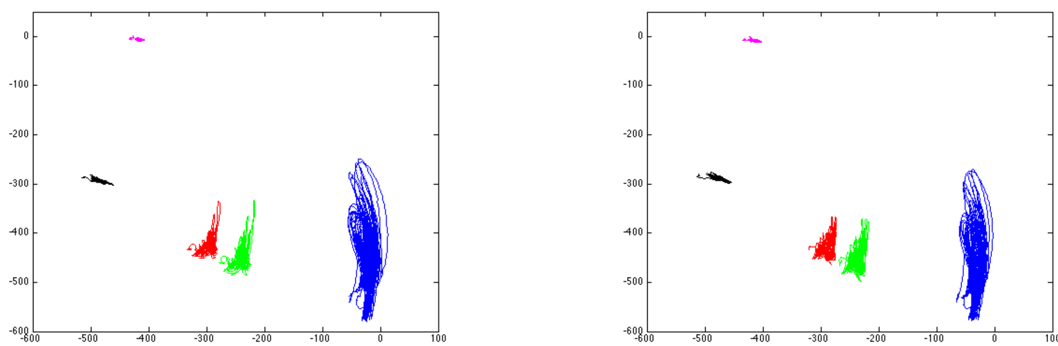
The motion trajectories of the left- and right-arms of P-C display a high level of symmetry, with the most observable differences appearing in the forearm and wrist (figure 3.10). By superimposing the left- and right-mallet trajectories over one another (figure 3.11a), we can see that the two share a very similar shape. The only differences arising here stem from the the fact that the left-mallet is shifted to the *right* along the x-axis.

Stroke Strike Location

The controlled and subtle performance gestures of P-C take on a slightly more erratic characteristic when they are viewed from the transverse plane (figure 3.11b). The striking locations once again show that the left-mallet is travelling away from the performer more than the right-mallet. Furthermore, P-C exhibits a striking location within the minimum and maximum y-dimensions. Regarding the striking area of each mallet, P-C does not demonstrate the level of symmetry seen from the sagittal perspective. The left-mallet occupies a striking area 52.6% larger than that of the right-mallet, which ranks as the 2nd greatest difference among the participants. When referring to table 3.2, we can see that although P-C exhibits a large difference between the left- and right-sides in striking area, the overall size (33.7 mm^2 for the left-side and 21.6 mm^2 for the right-side) is quite small compared to the other participants. For example, the average striking area for the right-hand among Participants 1, 2, 4, 5, and 6 is 143.1 mm^2. This is more than 6.5 times the size for Participant C at 21.6 mm^2.

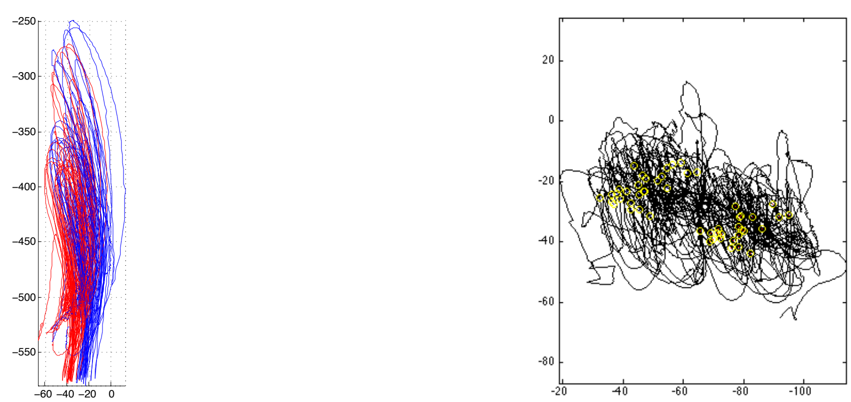
Standard Deviation of the Hands and Body

Given that P-C revealed little differences between the hands regarding the trajectory of the hands, it should not come as a surprise that the calculated STD values for the hands do not vary greatly (figure 3.18). In fact, P-C has the lowest STD difference between the hands' vertical movement, with the left-hand receiving a figure only 5.3% than the right. P-C shows an extraordinary ability to match gestural movements between the hands. Investigating the



(a) Left Arm (b) Right Arm

Fig. 3.10 Participant C's left- and right-arm trajectories. The perspective of the visualization is from the sagittal plane. Units displayed are in millimetres. The following markers are differentiated by color: *Magenta* = Shoulder, *Black* = Elbow, *Red* = Forearm, *Green* = Wrist, and *Blue* = Mallet.



(a) Superimposed Left and Right Mallets

(b) Transverse Trajectory and Strike Points

Fig. 3.11 In figure 3.11a the left and right mallets of Participant C are superimposed. Axes are in millimetres for both figures. In addition, for both figures *Blue* = Left and *Red* = Right. Figure 3.11a shows the trajectory from the sagittal plane. Figure 3.11b displays the trajectory of Participant C from the transverse plane where the striking locations can be seen in yellow.

STD of side-to-side (x-dimension) and front-to-back (y-dimension) movement, P-C reveals only 2.8% difference between the hands in the former and a 16.2% difference in the latter.

3.3.4 Participant D

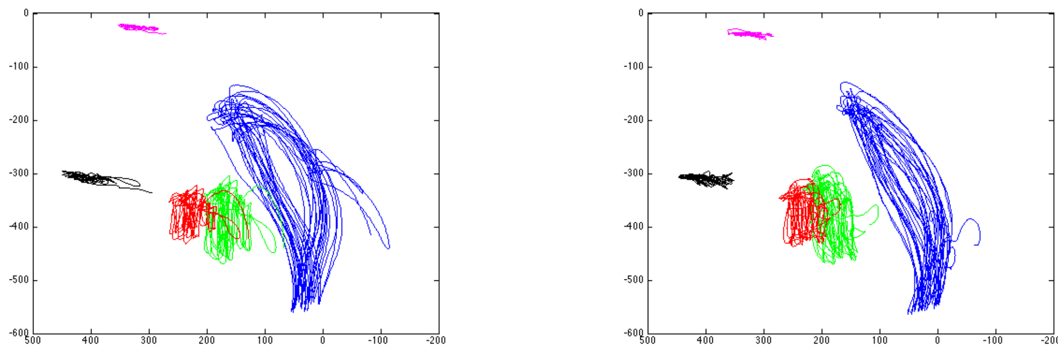
Participant D (P-D) of the neutral task is a self-described right-handed player and a first year Masters of Music student at McGill University. Regarding experience, P-D had received percussion training for 13 years prior to the study, the past 4 of which included specific timpani instruction. The grip method used by participant P-D was a personally-adapted hybrid of German and American grips.

Video Annotation Observations

Based on the video analysis and annotation, P-D exhibits a light touch in performance, with a strong desire to adhere to the the given tempo (despite the instruction that the given tempo is only a suggestion). Given P-D's level of training, this did not negatively affect the technical quality of the neutral task performance. Regarding the notion of ancillary movement [58], which describes a motion not principally related to sound creation, little expressive motion can be detected in this task. Overall, differences between each hand are difficult to distinguish through video analysis. The hands appear to move with a very similar trajectory.

Stroke Trajectory

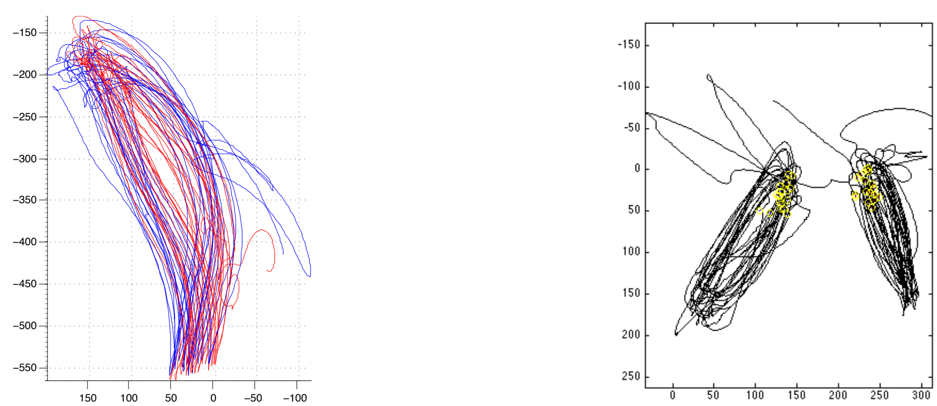
While any obvious differences between the left- and right-hands could not be observed directly from the video annotation analysis, subtle yet clear distinctions in the behaviour between the hands could be seen in the motion capture data. Isolating segments of the mallet, wrist, forearm, and elbow, then plotting their trajectories from the sagittal plane reveals a distinction in the gestural profiles between the left- and right- sides. This can be seen in figures 3.12 and 3.13a. Starting with the mallet trajectory, the left mallet performs a slightly larger *loop* in the cycle of each stroke. The right mallet displays a more linear gesture profile, meaning the mallet closely follows a vertical up-and-down movement. Each hand consists of a slight preparatory loop at the maximum height of each stroke. Overall, P-D displays a strong similarity in stroke height between left- and right-mallets. As seen in table 3.2, the right-mallet only travels 1.3% higher (5.6 mm) than the left-mallet in



(a) Left Arm

(b) Right Arm

Fig. 3.12 Participant D's left- and right-arm trajectories. The perspective of the visualization is from the sagittal plane. Units displayed are in millimetres. The following markers are differentiated by color: *Magenta* = Shoulder, *Black* = Elbow, *Red* = Forearm, *Green* = Wrist, and *Blue* = Mallet.



(a) Superimposed Left and Right Mallets

(b) Transverse Trajectory and Strike Points

Fig. 3.13 In figure 3.13a the left and right mallets of Participant D are superimposed. Axes are in millimetres for both figures. In addition, for both figures *Blue* = Left and *Red* = Right. Figure 3.13a shows the trajectory from the sagittal plane. Figure 3.13b displays the trajectory of Participant D from the transverse plane where the striking locations can be seen in yellow.

maximum height. On average, the right-mallet travels 1.6% higher (6.1 mm) than the left-mallet. Relative to the other participants, P-D displayed the closest similarity in maximum and average stroke height between the hands.

Striking Location

While the stroke trajectory from the sagittal plane reveals a slight level of asymmetry, views from the transverse plane reinforce previously stated observations. In addition to the trajectory of the mallets, the strike points on the drum-head have been visualized. This can be seen in figure 3.13b. The overall profile of the left mallet from the top-down transverse perspective reveals once again a tighter sense of control over the right mallet. The left mallet swings further off to the side of the performer, while the distribution of strike-points cover a slightly larger area than that of the right-hand. This is where the largest recorded difference between the hands of P-D can be seen. The left-mallet striking area is 19.3% larger (25.7 mm^2) than the right. Again, when considering the other participants, P-D exhibited the smallest difference in striking area between the left- and right-sides.

Standard Deviation of the Hands and Body

A first look at the standard deviation (figure 3.18) displays the extent of motion of the left- and right- mallets, as well as the sternum which is located in the upper torso. This central marker was positioned to display the extent of bodily movement relative to the mallets. In the case of P-D, the standard deviation of the left-mallet exceeds that of the right-mallet in both the x- and y-dimensions, reinforcing observations found in the previous examples. In the case of the z-dimension (stick height), we find that the right-mallet exceeds the left-mallet, suggesting greater variations of movement at the maximum height of each stroke. When the observing relative STD between the hands, P-D ranks 4th out of 6, with a calculated difference of 18% relative to the other participants. Regarding the x- and y-dimensions, P-D displays a slight difference between the hands in the former (10.9%) and a very large difference in the latter (55.1%).

3.3.5 Participant E

A self-determined right-handed player, Participant E (P-E) was another first year Masters of Music Student. At the time of the experiment, P-E had received 12 years of formal training in percussion performance. Timpani had been covered in 9 of those years leading up to the experimentation. Regarding grip technique, P-E described the approach as a hybrid-grip, showing traits of both German and French technique.

Video Annotation Observations

Preliminary inspection of the video revealed that P-E performed the neutral task with a predominantly French -technique approach. The slight deviation from French in P-E's technique appeared as a slight tilt of the wrists, showing a slight influence of German grip technique. The execution of the neutral task in this case was performed with relative ease. The participant displayed a rigorous approach in performance, as each performed gesture differed very little from the one preceding before it. The vertical attack on the drum-head was nearly linear. Each stroke was executed with a snap of the wrist, sending the mallet down towards the drum with a direct and pointed sound. The quick release off the drum-head, which characterized P-E's technique in the neutral task is a common trait of French grip.

Regarding the behaviour of each hand separately, slight differences could be seen in the case of P-E. As a self-determined right-handed performer, P-E's left-hand tends to follow the right when leading into a strike. As the right-hand approaches the drum-head, the left-hand seems to mimic the path of the right, stopping several centimetres before making an actual strike. When the left-hand is executing a strike, the right-hand appears to *ignore* the action of the left. Whereas the left follows the right as is passes by en route to a drum strike, the right does not reciprocate this action. This result is consistent with observations made in chapter 2, where figure 2.8.

Stroke Trajectory

Consulting trajectory plots of both the left- and right-arms reinforces observations noted in the video annotation. A study of the left-arm reveals in detail how the left-hand follows the right. While the main preparatory loop in the stroke is clear, the secondary loop mimicking the right-hand can be seen in figures 3.14 and 3.15a. This secondary stroke in the left-hand is self-contained within the maximum boundaries of the primary stroke (*i.e.* performance stroke). When attention is turned to the left-wrist, forearm, and elbow, artifacts of the secondary stroke are also apparent.

When the left-arm is compared to the right-arm, a greater sense of the presence of the left-arm's mimicking behaviour is apparent. The right-mallet moves with a clear and compact trajectory with little variation. The right-arm's movement is clear, showing that the right-handed P-E has a more developed technical approach in comparison to the left-hand. The right-wrist, forearm, and elbow all resemble the nature of the right-mallet trajectory.

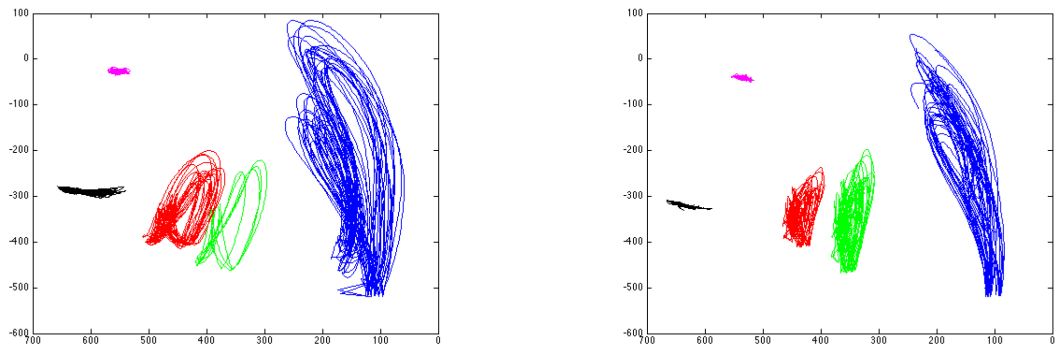
The maximum height differences between the hands show that the left-mallet reaches only 3.1% higher (17.8 mm) than the right-mallet. The left-mallet achieved a height 9.2% higher (45.5 mm) than the right-mallet. Despite the recorded differences between the left- and right-sides, P-E ranked second out of the 6 participants in this analysis regarding the similarity between maximum and average stroke height.

Striking Location

A projection of P-E's left- and right-handed strike locations on the transverse plane presents the extent to which the motion differs regarding *side-to-side* movement of the hands (figure 3.15b). The left-side, keeping in line with observations discussed previously, displays much more varied movement compared to the right. When observing the striking area between the left- and right-sides of P-E, we can see that right occupies an area 36% larger (24.9 mm^2) than the left. This difference is the 3rd largest within the participant group.

Standard Deviation of the Hands and Body

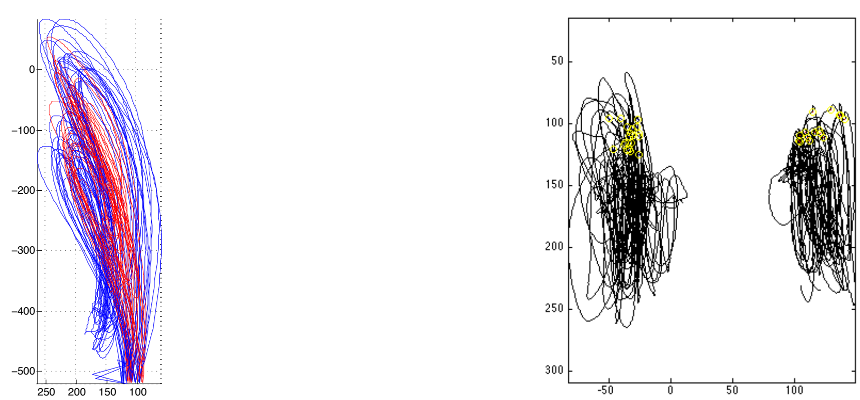
Regarding the standard deviation (STD) in the left- and right-hands, the left-hand clearly contains more excessive movement than the right (figure 3.18). This can potentially be explained by the gestural mimicking the left-hand exhibits when the right-hand performs. When the calculated STD between each hand is compared directly we see a 39.5% difference between the hands. This difference ranks 1st out of the 6 participants. Looking at the *side-to-side* movement (x-dimension) of P-E's hand, the overall difference between STD of the hands is much smaller, with a 10.1% difference between the hands. The left-hand is again found to contain the larger variance in movement, but to a lesser degree. Regarding movement *front-to-back* from the front of the body, the difference is still larger in the left-hand with a difference compared to the right-hand at 14.9% of the calculated STD.



(a) Left Arm

(b) Right Arm

Fig. 3.14 Participant E's left- and right-arm trajectories. The perspective of the visualization is from the sagittal plane. Units displayed are in millimetres. The following markers are differentiated by color: *Magenta* = Shoulder, *Black* = Elbow, *Red* = Forearm, *Green* = Wrist, and *Blue* = Mallet.



(a) Superimposed Left and Right Mallets

(b) Transverse Trajectory and Strike Points

Fig. 3.15 In figure 3.15a the left and right mallets of Participant E are superimposed. Axes are in millimetres for both figures. In addition, for both figures *Blue* = Left and *Red* = Right. Figure 3.15a shows the trajectory from the sagittal plane. Figure 3.15b displays the trajectory of Participant E from the transverse plane where the striking locations can be seen in yellow.

3.3.6 Participant F

While 5 out of the 6 participants were current percussion students in pursuit of (or beyond) their masters degree in performance, Participant F (P-F) is unique in that this individual is a composer. P-F achieved a Bachelors of Performance degree before studying composition at McGill University, and still performs percussion as an improviser on a frequent basis. The inclusion of P-F in the study provides an interesting view outside the disciplined realm of contemporary percussion performance, where technical approaches are constantly critiqued. P-F had received 11 years of percussion instruction before participating in the study, 9 of which included timpani training. In addition, P-F is a self-described right-handed performer.

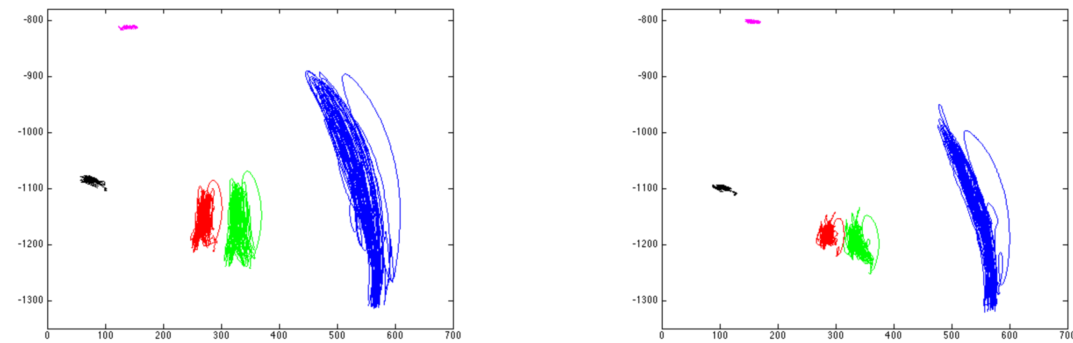
Video Annotation Observations

An overview of the video recorded during P-F's motion capture session reveals a few interesting observations. When considering the technical grip used by P-F (table 3.1), there appears to be slight tilt in the hands when approaching the drum with both hands. The slightly flatter hold of the sticks could be the result of P-F's drum-set playing, where performances require less of a *French*-style grip. Throughout the performance of the neutral task, P-F's technique appears to be quite symmetrical, and does not vary greatly when considering the x-dimension (side-to-side). The strokes on both sides of P-F appear to move close to vertically.

Stroke Trajectory

The stroke trajectories of the left- and right-arms (figure 3.16) show that there slight dissimilarities in trajectory. The most salient and apparent difference between the hands can be seen in the form of the maximum stroke height. While most performers' mallet trajectory contains a *preparatory loop* in between strikes of the drum, P-F's technical approach is very tight. A comparison between the trajectories of the left- and right-mallets in figure 3.17a shows that the two sides contain a very similar form.

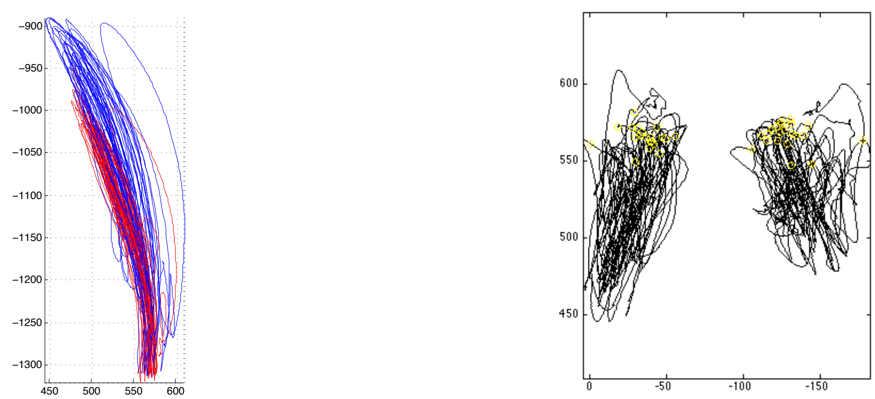
Most variation in this case appears in the form of stroke height. The maximum stroke height of the left-mallet was 18.9% higher (70 mm) than the right. The average stroke was higher with the left-mallet as well, achieving a distance 28% higher (89 mm) than the



(a) Left Arm

(b) Right Arm

Fig. 3.16 Participant F's left- and right-arm trajectories. The perspective of the visualization is from the sagittal plane. Units displayed are in millimetres. The following markers are differentiated by color: *Magenta* = Shoulder, *Black* = Elbow, *Red* = Forearm, *Green* = Wrist, and *Blue* = Mallet.



(a) Superimposed Left and Right Mallets

(b) Transverse Trajectory and Strike Points

Fig. 3.17 In figure 3.17a the left and right mallets of Participant F are superimposed. Axes are in millimetres for both figures. In addition, for both figures *Blue* = Left and *Red* = Right. Figure 3.17a shows the trajectory from the sagittal plane. Figure 3.17b displays the trajectory of Participant F from the transverse plane where the striking locations can be seen in yellow.

right-mallet. The differences between the left- and right-sides maximum and average mallet height for P-F were the largest of the 6 participants.

Stroke Strike Location

Turning our view to the transverse plane of P-F, a better perspective of the x-dimension and y-dimension can be observed (figure 3.17b). The left-hand occupies a larger range of motion compared to the right in the y-dimension. As opposed to P-C, we can see that P-F's striking locations on the drum-head appear in most cases at the maximum y-distance (the distance away from the performer). When the striking areas of the left- and right-sides are compared, the right occupies a space 22.1% larger than the left. This is the 2nd smallest difference in striking area among the 6 participants, which is a departure from the very large differences observed in stroke height.

Standard Deviation of the Hands and Body

With the analysis of stroke trajectory and strike points of P-F, slight asymmetries between the left- and right-sides are apparent (figure 3.18), yet the extent of these differences can best be observed when the standard deviation between the hands is calculated. In this case, P-F ranks 2nd out of the 6 participants with the STD difference in the left-hand at 22.2% more than the right. The increased variation in the height (z-dimension) between the hands seems to account for the extent of difference in STD.

3.4 Discussion

The results from the neutral task show that the employed movement strategies between the left- and right-sides of the body are far from symmetrical in form, even when performing a neutral task. In this exercise, the requirements of the left- and right-sides are identical. The task of performing alternating strokes on a single timpani does not contain any inherent bias towards either side of the body. Furthermore, the observed effects of handedness in each participant seem to be independent of the individual's experience, technical grip, and even preferred-hand. The gestural asymmetries reviewed in this chapter add to the ever-changing scope of laterality in human behaviour. In the following subsections, salient trends from table 3.2 will be discussed in detail.

3.4.1 Experience and Handedness

The results from the neutral task indicated that experience did not play an important role in determining the maximum stroke height, average stroke height, and striking area. For example, the two left-handed participants of the neutral task also represented the two extremes with regards to experience. P-B had received 6 years of training prior to the experiment, and P-A had received 17 years of training. What is interesting is that P-A exhibited some of the largest measured differences between the hands in the neutral task. The preferred left-hand of P-A led in stroke height maximum, average stroke height, and striking location area, while P-B's preferred left-hand only led in stroke area. Previous research has shown that more attention is placed on the preferred-hand in a bi-manual task [42], suggesting that wider range of motion seen in P-A's performances were intentional. Lesser movement which was seen in the non-preferred hand of P-A could have been due to lack of attention.

When the gestural profiles of P-B and P-A are taken into account, we can see that while P-A exhibited greater values in the measured categories of the left- and right-sides, the geometrical shape of P-A's left- and right-sides gestural movement is very similar. As previously discussed in the results, P-A similarity with regards to gestural profile only seemed to differ in scale. For P-B, the differences in gestural profiles profiles of the left- and right-sides are very different, and seem to consist of two separate movement strategies. The disparity in gestural movement between P-B's left- and right-sides may be related to experience. While no known studies have approached handedness and gestural trajectory, research has shown that experience enhances bi-manual coordination of the hands [21] [22]. These findings could also be applied to P-A, who displayed the most consistent gestural approach in the neutral task, suggesting that the uniformity between the left- and right-sides is a product of experience.

Still, it appears that when the differences between measured maxima of the left- and right-sides are compared, experience does not affect the result. P-D, who was a right-handed individual, contained the smallest differences between the hands in all of the measured categories. Regarding experience, P-D was 3rd among the 6 participants with 13 years of percussion training (but just 4 years of timpani instruction).

3.4.2 Preferred-hand Use

The mixture of preferred-hand and non-preferred hand use among the 6 participants in the neutral task was diverse across experience, handedness, and grips. While the measured figures were unique among each participant, there were trends regarding which categories were led by the preferred or non-preferred hand. One particular combination included half of the participants. This group includes two right-handed performers (P-E, P-F) and one left-handed performer (P-B). Each of these participants performed larger maximum and average stroke heights with their non-preferred hand, while the performance area for the preferred-hand was larger. These findings suggest that the non-preferred hand reached a higher stroke on average, yet occupied a smaller strike area. This is interesting given that an individual has a higher level of motor control over the preferred side [1]. As a percussionist, performing a higher stroke can introduce more risk of making an error. The stroke preparation is an essential facet of percussion technique. Once the mallet or hand has reached the drum-head, there are no further opportunities to sustain the sound.

Another interesting observation regarding the preferred-hand stems from the timpani study in chapter 2. In figure 2.8, it was noted that the non-preferred hand would tend to follow the preferred-hand in the *preparatory loop* phase of the stroke. This action was not reciprocated by the preferred-hand, which suggests it takes on leading-role in performing. Participants A, B, and F performed especially large preparatory loops in the upper section of their strokes. In each of their cases, the preferred-hand performed the slightly larger looping gesture. Participant D is interesting in that a large looping gesture is performed, but the larger gesture is in the non-preferred hand. This suggests that while handedness plays an important role in creating gestural asymmetry, hand-preference may not be sufficient in determining which hand performs the larger or smaller gesture.

3.5 Conclusion

The neutral task was designed to fit within the context of a larger experiment investigating the effects of handedness in percussion performance. Results from this experiment suggest that a seemingly simple task with equal requirements for each hand does not elicit similar responses. The results confirm the predictions described in section 3.2.4.

The research of Sofia Dahl [15] has shown that different movement strategies are employed by percussionists to execute the same task. A drum-set player will perform quite differently from an orchestral timpanist. Furthermore, the preferred-hand has shown itself to be more regular at producing rhythm [37] [42] [43]. Our research is novel, and contextualizes previous findings within the context of handedness (regarding [15]) and percussion performance (regarding [37] [42] [43]). These results reinforce observations made in chapter 2, showing that hand-to-hand differences in a symmetrical bi-manual task are most likely a result of one's handedness.

The effects of handedness are wide-spread and affect each participant uniquely. The gestural form of each hand takes on its own qualities, which is most likely a product of the individual's experiences and musical preferences. Furthermore, while there was a clear difference in each of the criteria shown in table 3.2, the distribution of extrema (*e.x.* maximum stroke height) was equally found in preferred- and non-preferred hands. Handedness seems to be the cause of asymmetrical movement, but it appears personal style may govern which hand performs the larger movement.

Throughout one's career, a percussionist is tasked with developing a technical approach which blends harmoniously with his or her own body. Absolute symmetry is almost never the goal when approaching performance technique, and as discussed in chapter 2, many instruments cannot support such an approach to begin with. The main advantage towards a uniformity in the hand's technique and gestural profile lies in the fact that it allows the performer to perform in a flexible and relaxed manner. Modern percussion repertoire often contains harsh technical demands which constantly push the boundaries of a performer's capabilities. When a single hand is relied upon too frequently or forced into playing too quickly, poor musicality is often the result. Even worse, injury can arise due to tension and poor form.

Chapter 4 will provide a closer examination of the effects of handedness within the context of musical sight-reading, with the added benefit of a larger population of performers. While this chapter has focused more on the gestural form of each participant using motion capture, the next chapter will look at how note function affects when each of the hands are used. The neutral task presented here was a simple one: Alternate the use of the hands, with no musical variation or notation whatsoever. It is a telling fact, however, that each participant began the neutral task with their preferred-hand, without being prompted to do so.

Measurement	Participant					
	A	B	C	D	E	F
Preferred Hand	Left	Left	Right	Right	Right	Right
Grip Style	Ger/Fra	Ger	Fra	Am/Ger	Am/Fra	Am/Fra
L Max Stroke Distance	732	576.4	333.4	429.8	591.5	441
R Max Stroke Distance	628	629.3	309.8	435.4	573.7	371
L Mean Stroke Distance	667.5	489.9	239.3	385.7	538.6	406.4
R Mean Stroke Distance	589	529.9	224	391.8	493.1	317.4
L Strike Area	127.2	266.3	33.7	158.7	69.3	176.9
R Strike Area	71.7	200.3	21.6	133	94.2	216.1
% Difference Max Distance	16.6%	9.2%	7.6%	1.3%	3.1%	18.9%
% Difference Mean Distance	13.3%	8.2%	6.8%	1.6%	9.2%	28%
% Difference Striking Area	77.4%	33%	56.2%	19.3%	36%	22.1%
Max Stroke Difference Rank	2 (P)	3 (NP)	4 (NP)	6 (P)	5 (NP)	1 (NP)
Mean Stroke Difference Rank	2 (P)	4 (NP)	5 (NP)	6 (P)	3 (NP)	1 (NP)
Strike Area Difference Rank	1 (P)	4 (P)	2 (NP)	6 (NP)	3 (P)	5 (P)

Table 3.2 This table present the recorded maximum stroke distances (from the drum-head to the peak height of the mallet), the average stroke distance, and the striking area on the surface of the drum-head for each participant. From these figures, the % difference between the hands in the maximum distance, average distance, and striking area of each stroke is produced. Rankings at the bottom of the table are based on the % difference figures, with the largest difference between the hands relative to the other participants receiving the lowest ranking. Next to the ranking is an indicator specifying the hand which produced the largest difference in the given category (**P** for preferred-hand and **NP** for the non-preferred hand.). All measurements are presented in *millimetres* (areas are in mm^2). *Participant E was not included in this study due to issues with the motion capture data.*

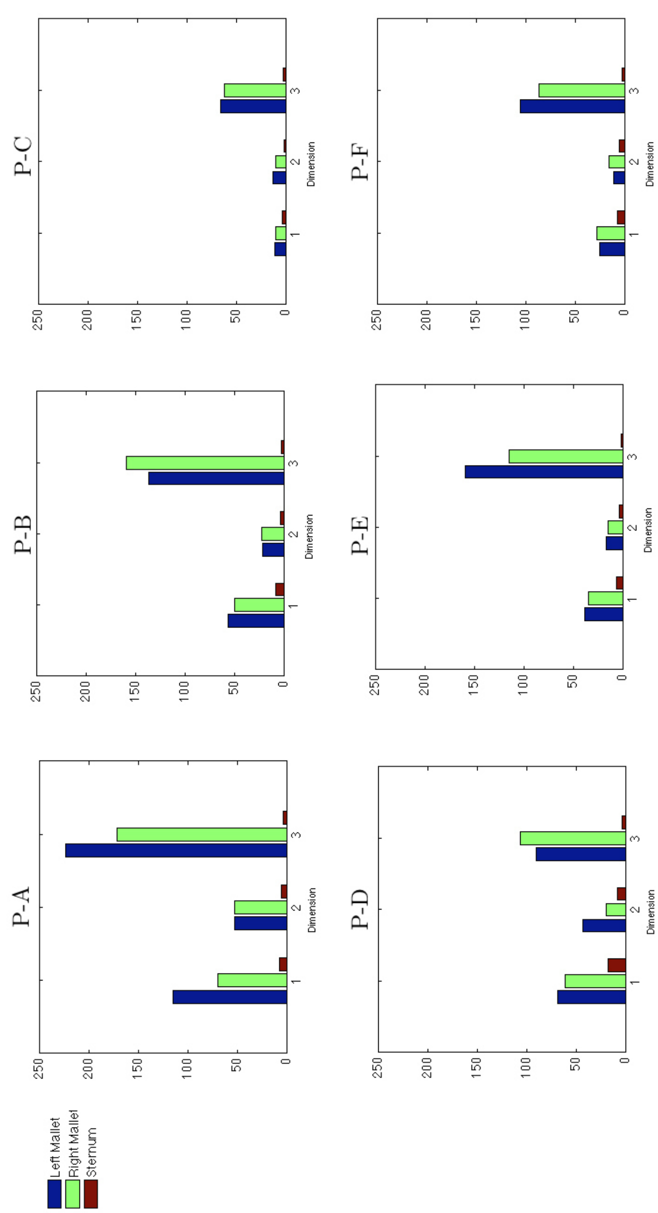


Fig. 3.18 This diagram displays the calculated standard deviation for each participant of the neutral task. The calculations and graph were created with the MoCap Toolbox [7]. Dimension 1 corresponds to x, 2 corresponds y, and 3 corresponds to z. Units are presented in millimetres along the y-axes.

Chapter 4

Handedness in Percussion Sight-Reading

This chapter presents the the results of the second experiment on the effects of handedness in percussion performance. Using sight-reading as method of distracting the performer, this experiment sought to reveal the instantaneous stick ordering choices of the left- and right-hands for 9 different participants. This experiment immediately followed the neutral task experiment previously discussed in chapter 3.

We hypothesized that, by providing the participants with a progressively difficult sight-reading etude, the effects of handedness in relation to an unrehearsed score could be observed. An active task such as sight-reading requires the participant to issue automatic responses to the score. In this case, the stick ordering choices reflect how handedness effects each participant with regards to timing. As will be discussed, an original rhythmic etude was developed to specifically test each participants timing.

4.1 Sight-Reading

Sight-reading is considered to be one of the most basic and crucial musical skill sets. The ability to read unrehearsed music demonstrates numerous mental processes involving active-memory, visual decoding, and fine motor skills [59]. Literature on the matter is diverse, with studies seeking to validate certain mental encoding functions, understand how experience effects reading abilities, and determining how skills are used with increasing difficulty.

In relation to handedness, current studies show that sinistral performers may have an inherent advantage over their dextral counterparts in sight-reading [60]. Other research in musical sight-reading has shown that as the complexity in sight-reading music increases, the necessary skills required from the performer move from an emphasis on general instrumental expertise to the psycho-motor movement and information processing [61].

4.2 Study in Percussion Sight-reading

Although there have been many studies regarding the effects of handedness in tapping tasks, literature is virtually non-existent when approaching the effects of handedness in percussion performance. Given the similarities between tapping and percussion performance, it seems appropriate to apply these findings in an investigation of handedness in a percussion performance setting.

4.2.1 Methodology

In a motion capture laboratory, 9 percussionists with at least a single year of university-level training were asked to perform a series of tasks on a single 29-inch timpani. As described earlier in chapter 3, the participants were recorded with motion capture cameras which were synchronized by an external clock with audio and video footage. A sight-reading task was performed consisting of no dynamic or articulation markings. A metronome of 90 beats per minute was used to count in the performers, and was switched off after the 4th measure. To analyse the performances, video footage of each performer was extensively reviewed in order to compile statistics on left and right hand strokes, identify errors in the performer's playing, and search for other unforeseen effects of handedness.

4.2.2 Sight-Reading Score

The score used for the sight-reading task in this experiment was designed specifically with handedness in mind. The timpani and sight-reading score do not contain any inherent bias towards the left or right sides. In addition, while remaining a challenge to read, the sight-reading score could easily be performed with simple alternating strokes by both left- and right-handed participants.

In an attempt to employ previous findings regarding handedness and timing, the overall structure of the sight-reading task consisted of several sections which gradually increased in levels of syncopation and rhythmic complexity. This can be seen in appendix B, figure B.1 and figure B.2. The rhythmic content which comprised the notation was broken down into four major categories based on beat function. This categorization includes: large beats, off-beats, subdivisions, and irregular rhythms.

The following descriptions will use the *1-e-and-a* beat counting strategy to describe their beat function. Large beats are quarter note rhythms, the largest beat found in the sight-reading study. This category contained a subcategory, weak beats. Large beats are considered those which fall on beats 1 and 3, while weak beats (or back beats) fall on 2 and 4. The off-beat category consisted of 8th-notes falling in-between the quarter-note values. This consists of rhythms on the *and* beat. The subdivision category contained sixteenth-note beats which fell in-between the 8th-note and quarter-note rhythms. The final category, irregular rhythms (also known as *tuplets*), are rhythmic structures which fall outside of the beat matrix dictated by the time signature. This includes quintuplet and triplet figures (e.g. 5:2, 3:4 patterns). The frequency and function of each rhythmic element can be seen in table 4.1. Overall, the sight-reading score consists of 7 time-signature changes, 21 measures, and 103 playable notes.

Table 4.1: Distribution of Rhythmic Elements

Element	**Frequency**	**Function**
Down-Beat	20.59%	Demarcates measures
Weak-Beat	20.59%	Basic beat marker
8th Note	26.47%	Introduces syncopation
16th Note	25.49%	Enhances metered complexity
Irregular	6.86%	Obscures metering

The sight-reading study structure consisted of four main sections which progressed from an emphasis on down-beats and weak-beats, to areas of rhythmic complexity featuring off-beats (8th-notes) and subdivisions (16th-notes), to the use of advanced syncopation and irregular rhythms. The structure also employed the use of three different time signatures (4/4, 3/4, and 2/4). With a simple introduction leading to areas of advanced rhythmic complexity, the sight-reading study was designed to challenge the plasticity of the performer's internal timing and to draw attention away from any expressive gestures.

4.3 Hypothesis

Given that sight-reading demands the immediate attention of the performer [59], it was hypothesized that:

- The preferred-hand would initiate the task
- The larger a given note's subdivision, the more likely it would be performed by the preferred-hand

The general foundation for the hypothesis relies on the notion that the preferred-hand is better at producing consistent rhythm, and that the non-preferred hand is better when automated [37] [42] [26]. Therefore, in the context of music, the larger a note's subdivision, the more likely it is to be performed by the preferred-hand. Because the music is being performed is unrehearsed, the participants in the experiment will focus their attention on the oncoming notes, requiring the hands to respond automatically.

With regards to ordering of the performed-hand, the term *sticking* will be used. This is the proper term percussionists use when referring to the process of choosing a stick (*i.e.* the left or right) to perform a given note.

4.4 Results

The sight-reading study produced many interesting observations on each player's hand preferences. Despite the sight-reading task's neutrality towards the left and right sides, observations from this study produced strong evidence of the effect of handedness on percussion performance.

The general performance quality from each participant was very high. Given the complexity of the sight-reading task, the participants maintained a professional level of concentration. While only a few errors were produced, the sound quality and overall musicality of each performers' reading was excellent. No major variations in tempo or dynamics were apparent in any of the performances.

When assessed from a performer's perspective, the variation in musical quality between each participant's performance was not substantial. The overall lack of egregious errors, coupled with a consistency of tempo in each performance allowed for direct comparisons focusing in the effects of handedness. While each individual exhibited their own unique

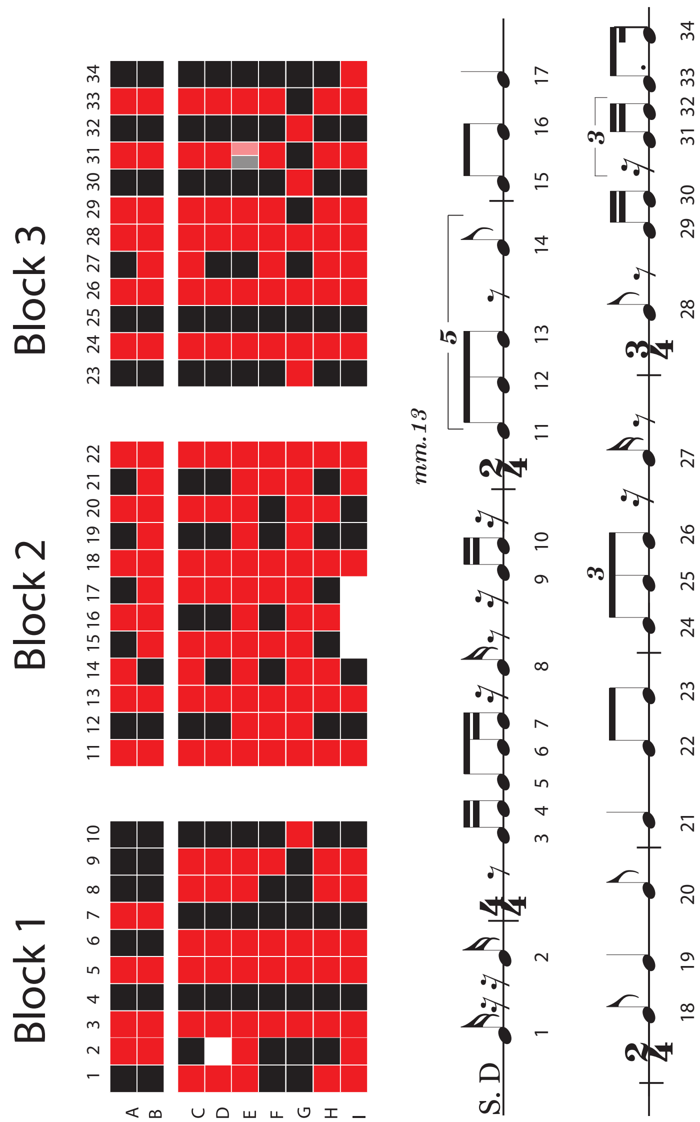


Fig. 4.1 This is a normalized beat matrix depicting the sticking choices from the corresponding notation below. Red boxes indicate the use of the preferred-hand. Black boxes indicates the use of the non-preferred hand. Players A and B are left-handed. Empty spaces are notes omitted by the participant. Gradient boxes are performed errors. Block 1 displays relative uniformity in hand choice. Block 2 displays the onset of extreme multi-strokes in players B, E, and G. Block 3 displays a relative return to uniform use of the hands in stick choice after re-establishment of the timing structure.

performance gesture, strong and clear similarities unite each of the performers with regards to the general use of the preferred-hand. A close look at local sections of the musical score reveal interesting divisions between the left- and right-handed performers.

4.4.1 Gestural Form and Function

The form and function of a participant's technical approach are two advantageous and insightful methods for analysing a given performance. The form, in this case, refers to the *gestural profile* (*i.e.* trajectory) of a given performer, while the function refers to when a particular hand is used. In the context of the sight-reading task, using the preferred-hand more on down-beats is a result of handedness with regards to function. The trajectory of the hand is the form. Therefore, it is possible for two participants to perform a task similarly with regards to function (using the same hand to perform), while the form of their technique can vary greatly. An example of this can be seen in figure 4.1, in beats 23-29. Participant B (left-handed) and F (right-handed) executed the segment of the sight-reading study with the exact same stick ordering. In fact, most participants in this segment relied upon their preferred-hand in a similar fashion. Yet, when we take a larger look at the technical form of participant's B and F's technique, we see that they are very different. Not only do their technical approaches differ, but each hand trajectory differs greatly as well. This can be seen in figure 4.2, while supporting observations on gestural hand differences are also reported on in chapters 2 and 3. The differences in form seen here offer just one look at the many possible different gestural profiles found in each performer. This reinforces previous findings which showed that performers use different movement strategies when executing the same task [15] [3].

4.4.2 Functional Roles of the Hands

Among some of the most interesting findings of this study include the fact that the preferred-hand was used a majority of the time when encountering strokes with the lowest time-subdivision (*i.e.* the largest time value). Down-beats received the largest percentage of strikes from the preferred-hand at 84.1%.

The weak-beat also drew a large majority of preferred-hand strikes from each participant, but at a less frequent rate. For weak-beats, the preferred-hand still performs a clear majority of the notes at 68.2%. Irregular beats, which require different time- keeping

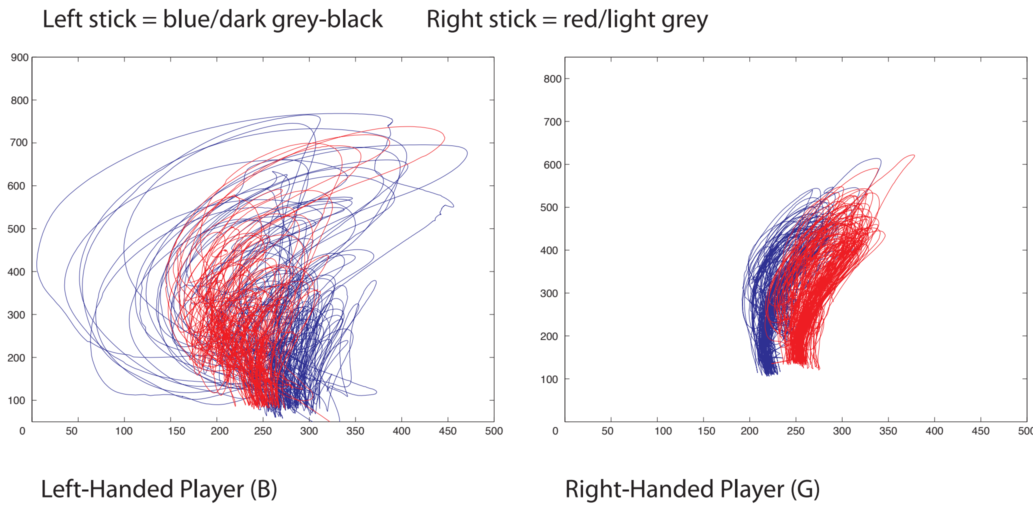


Fig. 4.2 Represented here is the cumulative tracing of both left and right sticks of Player B and Player F, viewed from the sagittal plane. The axes are shown are in mm.

strategies for performance, received 55.6% of strikes from the preferred-hand.

With regards to the non-preferred hand, the findings suggest that it receives secondary timing responsibilities, as the 8th-note and 16th-note subdivisions received 57.2% and 32.0% striking percentage from the preferred-hand, respectively. In figure 4.3, one can observe how the structural role of each rhythmic element affected the performers' use of the preferred-hand. As the beat-value moves from larger to smaller divisions, the preferred-hand's performance frequency decreased.

4.4.3 Comparisons Between Sinistral and Dextral Participants

In figure 4.4, a beat matrix containing the sticking choices for all down-beats and 16th-note subdivisions provides a useful tool for examining the macro and micro functional trends of the hands in the sight-reading task. A clear shift towards the use of the non-preferred hand can be seen. Most of the time, the use of the preferred-hand in the left- and right-handed players is similar, as the context of the down-beats and 16th-note subdivisions generally elicits similar responses from both groups. Nevertheless, there arise several instances where the left- (A and B) and right-handed (C-I) performers differ. In Block 2 of both the down-beat and 16th-note beat matrices, the sticking choice of players A and B is identical. Block 2 of the 16th-note segment represents the entire middle section of the sight-reading material, where the highest density of 16th-note subdivisions reside. Based on the designed beat-hierarchy, where down-beats fall on the largest beat indicator, it appears that participants A and B exhibited a higher level of alternate use of the hands in the middle section of the sight-reading task. Upon closer examination, a slight shift towards alternate (even) sticking choice can be recognized. For the entire sight-reading exercise, performers A and B used their preferred (left) hand 58.65% and 61.54% of the time respectively. In the center segment of the study, which includes the notes found in Block 2 of the figure 4.4 beat-matrix, the average for players A and B is 56.09% and 58.53%.

4.4.4 Multi-Strokes

Sequences of consecutive strokes (multi-strokes) were observed throughout the study, and were predominantly performed by the preferred-hand. A multi-stroke in percussion performance is generally defined as a series of 3 or more consecutive strokes performed with one hand.

Viewing figure 4.1 reveals many instances of multi-stickings with each hand, ranging from double-strokes to a series of 15. While multi-stickings can be observed in each hand, they are predominantly found in the preferred-hand.

Three of the longest series of multi-strokes (8, 12, and 15) directly followed the irregular rhythm found in figure 4.1. In Block 2 of the figure, participants B, E, and G can be observed performing their multi-strokes. In the corresponding score beneath the beat matrix, the right-handed performers E and G initialize beat 11 with their preferred-hand. Beat 11 was strategically placed to obfuscate the down-beat which many performers rely on to perform rhythms accurately. In the notes following the quintuplet, the downbeat reappears on beat 15, and moves into a simple syncopated rhythm. The quick changes between the 4/4, 5/2, and syncopated 2/4 meters offers an explanation towards the extreme multi-stickings of participants B, E, and G. In the case of B, who is a left-handed player, multi-sticking happens after the quintuplet, beginning on beat 15. The extreme multi-stickings could perhaps be interpreted as a manifestation of the participants attempting to re-establish (find) the down-beat.

In Block 3, a majority of the performers (all excluding participant G), tended to follow the same sticking pattern. In the notation, beats 23-29 cover the transition from duple to triple meters, where an irregular rhythm was used to obscure the transition. Most perform-

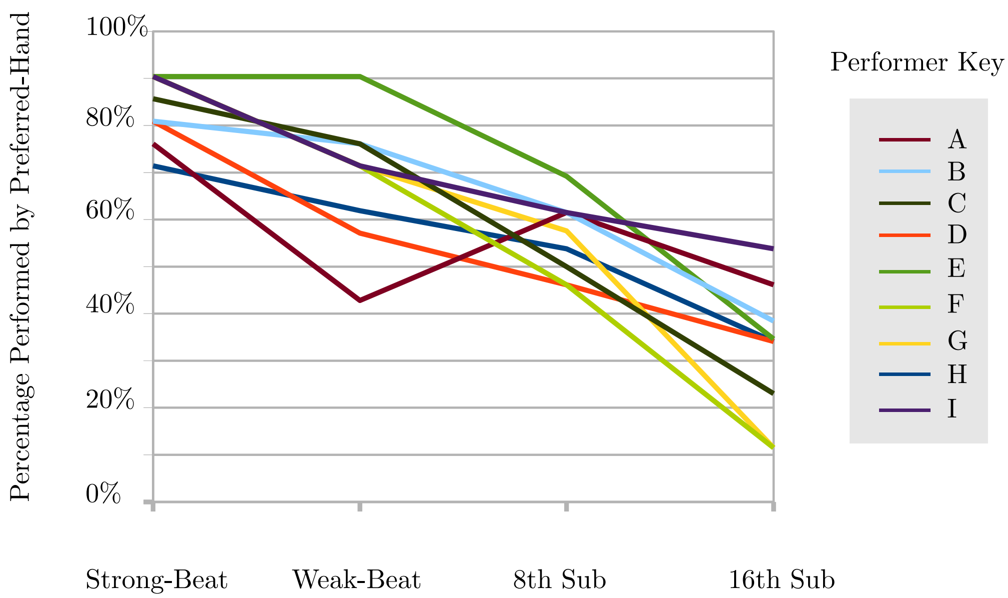


Fig. 4.3 Participant use of the preferred-hand for each participant. The x-axis displays the 4 beat structure elements, moving from the largest to smallest functional time division. The y-axis displays the % of times the preferred-hand was used to perform.

ers in Block 3, performed three or four of beats 26-29 with their preferred-hand. Those particular beats contain the back-end of a triplet and a variety of 8th- and 16th-note rests and rhythms. These notes require an expert sense of musical time to perform accurately. Most participants relied upon their preferred-hand to play this segment correctly.

4.5 Discussion

The findings show a clear trend towards the use of the preferred-hand in relation to the elements of rhythmic structure. This falls in line with the hypothesis (section 4.3), which stated that because the preferred-hand has been found to perform more consistent rhythms in bi-manual tapping tasks, it is likely the same would be true in a percussive musical setting. Each performer relied on the preferred-hand a majority of the time, because it was the hand which could be relied upon to execute the rhythm properly. It is also likely that if another rhythmic exercise were issued, but with time to review the notes, there would be a much more even distribution of performed notes between the hands.

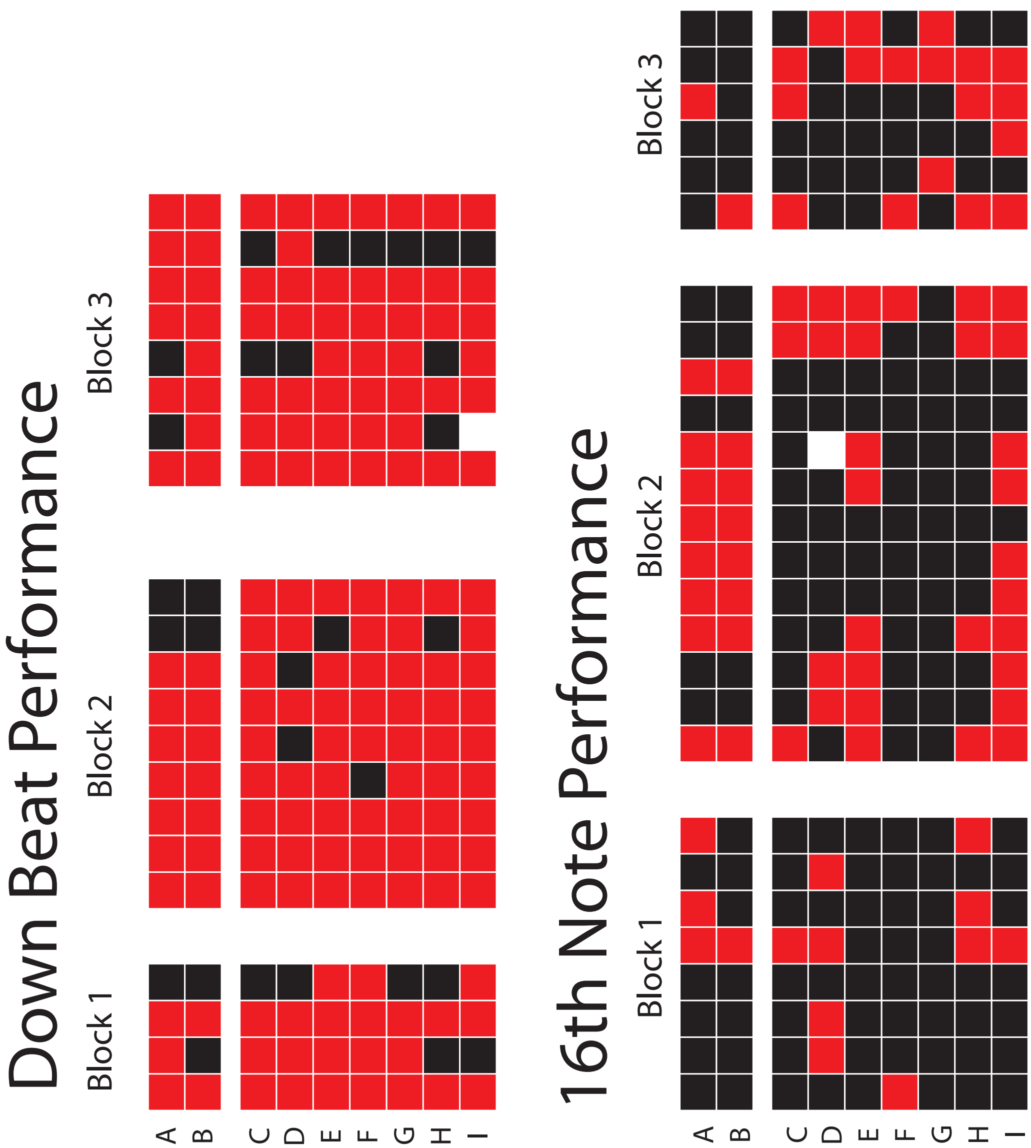


Fig. 4.4 This is a normalized beat matrix depicting the sticking choices of all down-beats and 16th-note subdivisions of the study. Red boxes indicate the use of the preferred-hand. Black boxes indicate the use of the non-preferred hand. Players A and B are left-handed. Blocks 1 and 3 in both matrices show unique sticking between all participants. Block 2 shows identical sinistral performer sticking.

Each of the participants had at least one year of university-level percussion training, and many had performed professionally in the past. In percussion pedagogy, the influence of handedness is generally assumed [62], and in many method books, students are instructed to work on the left-hand (an example of right-handed bias) much more than the right. Further instruction on the matter is seldom discussed in detail. In relation to the sound and gesture, some methods encourage a display of *evenness* [49] [48], which hints at the sense of symmetry in both the form and function of each hand.

Another topic of interest regarding handedness may lie within the realm of dynamic variation. In this study, the sight-reading score contained no dynamic changes, leaving the participants free to perform without any necessary changes in gait. Studies regarding the motion of the human body describe a distinct jump from one locomotive strategy to another (*e.x.* walking and running) when the necessary force for a given task is increased. This change in locomotive *phase* has also been shown in the hands [40]. Given the extent of handedness' roots in human physiological development, it would be logical to extend this study to include dynamic variation in the score.

4.5.1 Sinistral Differences

Any fundamental behavioral differences between sinistral and dextral participants has yet to be seen in this study. Handedness has a strong effect over the way we interact with the world, but whether one is left- or right-handed does not seem to matter. As mentioned in section 4.1, handedness may give left-handed individuals an advantage when sight-reading [60]. In general, left-handed persons are more apt to use either hand for a given action [1] [63], which in theory can make them more flexible when issuing responses. In a dextral-biased world, most left-handed individuals learn to adapt, and become much better than right-handers at using their non-preferred hand. More left-handed participants would be necessary to draw any definitive conclusions on their behaviour in this study.

4.5.2 Functional Roles of the Hands

The overwhelming percentage of 84.1% use of the preferred-hand on down-beats indicates that rhythmic structure plays a clear role with regards to hand-preference. Metric structures which either begin or mark the halfway point of a measure are heavily relied upon by the preferred-hand. With regards to 16th-note subdivisions, which were the lowest beat-structure, the preferred-hand was used only 32.0% of the time. The smaller the rhythmic element, the less likely it was to fall on a major subdivision. This suggests that these notes played a less critical role in the timekeeping strategies used by the performer. Furthermore, the fact that the preferred-hand was favoured so strongly supports the idea that handedness plays an integral part in timekeeping, which is closely linked to metric-structure. This notion is represented in figure 4.3, with greater details seen in the amalgamated beat matrix figure 4.4. Figure 4.4 also displays interesting departures from the left-handed performers (A and B) in Block 2, yet a continuation of this study with more left-handed participants is necessary for any conclusive findings.

4.5.3 Multi-Strokes

One can find examples of multi-stickings throughout the beat matrix in figure 4.1. Results show that the preferred-hand performed multi-stickings more frequently, and with much longer extremes. Given that the beat matrix shown in figure 4.1 coincides with the most challenging rhythms of the entire study, a link between the obfuscation of a clear down-beat and multi-stickings of the preferred-hand can be deduced.

A possible explanation for the observed multi-stickings in figure 4.1 could be that the obfuscation of the *1-e-and-a* beat counting strategy by the irregular rhythms (beats 11-14, 24-26, and 31-32) disrupted the performer's timekeeping, thus requiring the preferred-hand to work harder in order to restart the centralized-timing schedule.

Technically speaking, percussionists are often trained to perform double-strokes (two consecutive strokes) as way to execute fast passages, initiate rolls, and place special emphasis on notes, with multi-strokes serving more advanced and extended technical passages. The sight-reading score, at 90 beats per minute, is hardly fast enough at its most rapid segments to challenge a university-level performer beyond the point where simply alternating the sticks would not be practical. In most cases, the performer can rehearse, identify the strengths and weaknesses in their hands, and choose the most advantageous sticking order. Sticking is an important skill to develop as a player, and while many seek to achieve a level of technical proficiency where sticking may become irrelevant, the effect of handedness is usually too strong to overcome entirely.

4.6 Conclusion

Despite the awareness on the issue of handedness by percussionists and the neutrality towards lateralisation of the presented sight-reading task, the compulsion to rely on the preferred-hand in critical time-keeping strategies seems to reside deeply within each performer. While it has been shown that the preferred-hand is better at performing consistent rhythm, observations of these effects have only been made within the context of a tapping-task handedness evaluation setting. The findings of this experiment suggest that these results carry over into music notational function.

In addition, it appears as though high levels of training have not neutralized the effects of handedness regarding the form of each players technique. Although, it could be argued that the observed shift in function from the preferred-hand/down-beat to the non-preferred hand/subdivision relationship signals the possible influence of percussion training.

Chapter 5

Conclusion

This chapter serves as a comprehensive summary of the procedures and experimental results contained within this thesis. The *handedness in percussion performance* findings will be contextualized in reference to the hypotheses, while areas for future work and experimental improvements will be brought forth. Overall, the novelty of the experiments contained within this thesis will be highlighted.

5.1 Hypotheses

Attempting to bring together supporting results for this thesis' hypotheses was certainly a challenge. The field of laterality is, at its core, an interdisciplinary subject, which makes any form of standardization or agreement within the research community difficult. This lack of uniformity within the field has not gone unnoticed [32] [34] [31].

The deductions which informed the hypotheses of chapter 3, section 3.2.4 and chapter 4, section 4.3 were primarily guided by a select few who have had a significant impact on laterality research over the past 30 years.

Specifically, the tapping-task research by Michael Peters [37] [42], the handedness research by Marian Annett [30] [1] [27], and the gestural studies of percussionists by Sofia Dahl [15], directly informed the hypotheses and general research of this thesis. The work of Peters provided valuable insight into the relationship between the hands when faced with temporal tasks and contributed to the hypotheses related to handedness and rhythm (chapter 3 section 3.2.4 and chapter 4 section 4.3). Annett's authoritative texts on decades of handedness research informed the analysis methods employed in this thesis and helped steer the research of this thesis past the pitfalls located within the complicated field of laterality. Furthermore, the hypotheses (chapter 3 section 3.2.4) suggesting that the gestural behaviour of the left- and right-hands would differ would not have been predicted if it were not for the work of Sofia Dahl and the motion capture work of Alexander Bouënard (chapter 2, figure 2.8).

5.2 Experimental Results

In chapter 2, preliminary studies on the possible effects of handedness in percussion performance were presented. Two studies, one on the snare-drum and the other on timpani, were analysed with respect to the differences between the gestural movements of the hands. After discovering many differences between the left- and right-hands, including changes in gait during dynamic transitions, a detailed look into the physical differences between the left- and right-hands was performed in chapter 3.

The timpani was used in this case because it requires large gestural movements from the arms (relative to most other percussion instruments), allowing for relaxed and easily observable movement from the participants. The results of chapter 3 suggested that in symmetrical and neutral context (*i.e.* no indicated musical content besides a simple performance gesture), the hands contained many gestural differences across all performers, regardless of hand-preference, age, grip, or performance experience.

In chapter 4, an exploration of handedness in a sight-reading context was performed. After annotating video-documentation of 9 participant's performances of a uniquely designed score for this thesis, correlations between hand-preference and notational metric function were found. Across all participants, it was observed that the larger the beat denomination, the more likely the preferred-hand would perform it.

The asymmetry of physical movement between the hands reported upon in this chapter appeared to fall outside any findings in previous handedness and/or gestural studies. While differences in gestural movement between individual players had been documented [15], differences between the hands of a single player had not been studied. The nature of the gestural asymmetry between the hands was theorized to be caused by handedness, a subset of the greater field of laterality. Chapters 3 and 4 were specifically developed to research how handedness effects the gestural and functional performance strategies of percussion players.

Unexpected Results

The most unexpected results of the research contained in this thesis can be found in chapter 3. While predicting the gestural behaviour of an individual is quite difficult, the distribution of extrema (*e.x.* maximum stroke height, striking area) for the preferred- and non-preferred hands was interesting to observe. Each participant, left- or right-handed, contained his or her own mixture of preferred- or non-preferred hand-led categories. A look at the ranking of extrema between the participants in table 3.2 suggests that while handedness is likely the cause of the differences between the hands, whether that hand is the preferred- or non-preferred may not be a reliable factor in predicting which hand would perform the larger or smaller gesture.

5.3 Research Implications

The deep-lying effects of laterality on the human body have many important implications regarding our understanding of how people move and behave. Because of the widespread nature of laterality and its effects, a greater understanding of how the left- and right-sides of the body behave can enhance our self-awareness in a seemingly unlimited number of contexts.

5.3.1 Percussion Pedagogy

First and foremost, this thesis provides important and previously undocumented details of possible gestural differences between the left- and right-sides in the context of percussion performance. The analysis and results of the experimentation contained in this thesis are conducted from the perspective of a performer. The practical performance implications are the primary focus. Such documentation can serve as an invaluable tool for both teachers and performers. As discussed in chapter 2, the notion of symmetry in percussion performance is encouraged, but is seldom discussed beyond the notion of *evenness* [49] [48]. The evidence of handedness' influence on gestural form and function show how hands can differ in their behaviour. With these details, performers and teachers can enhance their decision-making regarding technical choices involving stick-ordering or instrumental set-up. Weaknesses can be better identified, and more efficient practice and lesson routines can be established, especially at the introductory level.

5.3.2 Gestural Modelling

Evidence of the wide-ranging effects of handedness in a bi-manual task, especially regarding hand trajectory, can be useful in attempts to virtually model the realistic movement of a human being. Attempts to create a physical model of a percussionist had previously been attempted [64]. Considering the differences between the trajectory and behaviour of the left- and right- sides of the body, taking into account the findings of this study could aid in the production of a more realistic virtual model.

Further attention to the gestural differences between the hands may be important in replicating an individual's particular style of *playing*. Evidence provided in chapter 4 suggests that while two individuals may perform with the exact same stick ordering, the ancillary movement [58] [16] may (and most likely will be) very different. Therefore, handedness in this case is not influencing *which* notes are struck, but *how*.

5.3.3 Instrument Design

Given that handedness holds a strong influence over how an individual issues responses with their hands, knowledge of these effects can be valuable when considering the design of a new digital musical instrument (DMI). Adapting the performance demands of a DMI to the capabilities of the performer can provide for enhanced gestural interactions [65]. The effects of handedness can certainly provide useful insight when designing the mapping strategy of a new DMI.

5.4 Future Work

The scope of the research contained within this thesis was primarily directed at observing how handedness can potentially affect an individual percussionist's performance.

5.4.1 Asymmetrical Tasks

As mentioned in chapter 2, the percussion family is diverse, containing many different instrument designs and technical approaches. While this thesis was primarily concerned with symmetrical bi-manual tasks on the timpani, there is room for experimentation concerning asymmetrical tasks in percussion as well. Outside the realm of membrane instruments (snare-drums, timpani, *etc.*), the percussion family is full of asymmetrically shaped instruments. Marimbas, a member of the keyboard family (seen in chapter 2) require different gestures from the left- and right-hands [46]. Furthermore, multi-percussion pieces contain collections of instruments, which can result in very different performance demands from each hand [47]. Future research in percussion performance could use the asymmetrical instruments to apply the findings of manual asymmetrical studies. Some of which have shown that in temporal based tasks, the arms are capable of forming cooperative and/or conflicting relationships [66].

5.4.2 Searching for Lefties

The primary experiments conducted in chapters 3 and 4 each contained two left-handed participants. It is clear that more left-handed performers are necessary to establish generalized conclusions regarding left-handed players. Despite having two left-handed players, it was clear that their sinistral orientation greatly affected their gestural trajectory and stick ordering. Each left-handed participant performed a clear majority of the notes from the sight-reading exercise with his or her left-hand, and appeared to issue responses to the hands in a different manner than their dextral counterparts. With such promising results, it would benefit the research of this thesis immensely to increase the number of left-handed participants in each experiment so that larger trends and tendencies can be identified.

5.4.3 Dance and Performance Art

Lastly, the physicality of percussion performance affords many windows of observation when considering the effects of handedness other types of performance. Given the potentially higher physical demands in dance and performance art, it may also prove to be interesting to investigate how handedness may hold an effect here. Popular contemporary choreography techniques rely on physical properties and natural bodily tendencies to inform the movements and trajectory of a performance [67]. Laterality itself can be observed more intensely here, as in dance and physical performance art, the entire body is often in play. Knowledge of these effects may potentially serve as an interesting tool for creative exploration and expression.

Appendix A

Motion Capture Protocol

This Appendix displays the Motion Capture Protocol which was developed for the research contained within this thesis. The protocol contains the detailed diagrams of the equipment, connections, and procedures necessary to replicate the methodology used to acquire data for the experiments in chapters 2, 3, and 4.

This protocol was developed by Benjamin Bacon, Julien Vogels, Catherine Massie-Laberge, and Carolina Brum Medeiros.

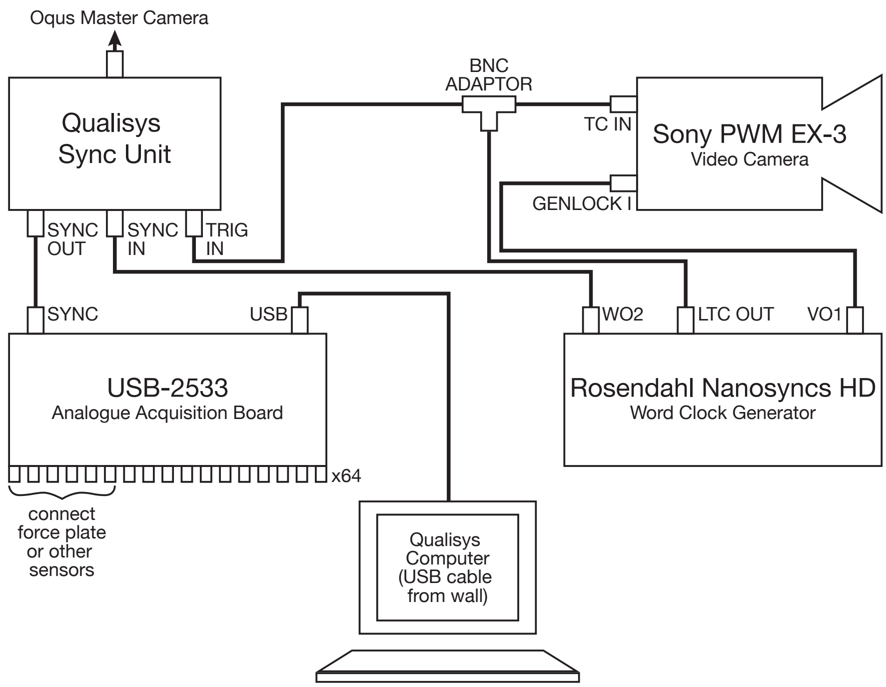
Fig. A.1 Page 1 of the Motion Capture Protocol.

MOTION CAPTURE – PROTOCOL

For general reference, consult the QTM User Manual. It can be downloaded on the CIRMMT booking website where you booked the lab.

Hardware

Hardware Wiring Scheme



Oqus 5 Cameras
- Number: At least two cameras required to recognize a point in 3D. The more cameras, the more accurate is the result.
- Positioning (p. 255 QTM User Manual)
- Angle: Best results when cameras are angled 60º (bad results under 30º)
- Focus: Blurred images contribute to marker trajectory swaps

Video camera:
- Adjust aperture, focus and zoom

Fig. A.2 Page 2 of the Motion Capture Protocol.

- Choose video format (1080p or 720p), it has to be 25 fps in order to work with the word clock
- Adjust audio level (manual = ext.; audio select = audio in; manual = in); use good headphones
- Use the zebra function (70% zebra level) to get the aperture right. The 70% zebra overlay should be visible slightly on the filmed subjects cheek.

<u>Force plate</u>
- Adjust grain (~5–10)
- Auto zero

<u>Electronic Sensor Input to USB-2533</u>
- Design your sensor circuit and test it (e.g., with an Arduino). Example: FSR circuit with a voltage divider
- Use a BNC Connector Probe (to be found in the Music Tech Electronics Lab) to connect the red connector to the measured voltage and the black connector to your circuit's ground. Example: Red connector between variable resistor and static resistor of voltage divider (where you would connect an Arduino's analog input), black to where you would connect the circuit to Arduino GND.
- Use CIRMMT's Lab Power Supply to power the circuit: Use two probes with either banana connectors or clamped connection and connect the power just as you would do with an Arduino (red is supply, black is ground). Turn the unit on, select the voltage (in V) and amount of current (in A), turn the output switch on (!). In our Arduino FSR example you would select 5V and about 40mA (keep it low, but the circuit will take what it needs).
- In the Qualisys Project Settings > Analog Boards > USB-2533 you can specify the input range (±10 V, ±5 V, ±2 V, ±1 V, ±0.5 V, ±0.2 V, and ±0.1V)
- Set the sample rate to the audio sample rate. Depending on the number of inputs you use, the sample rate can be as high as 1 MHz for 1 single input and 62.5kHz when all 16 inputs are in use.

<u>Nanosync</u>
- Video reference:
  - Internal
- SD video generator:
  - SD STD = PAL 25 locked
  - HD STD = 720 p or 1080 p according to your camera setup
  - FPS = 25
- Audio reference:
  - Follow video
- Sample rate:
  - 48 000 locked
- Multipliers:
  - WO 1-6 = x1
  - WO 7-8 = x1
  - AES x1

Fig. A.3 Page 3 of the Motion Capture Protocol.

- SPDIF x1
- USB = MTC to LCT
  - *(!) this setting doesn't store and has to be set every time you start the device. Otherwise, Qualisys won't store the SMPTE.*

D-Code Clap
- This professional movie scene clap let's you display the current timecode. It helps you keep organized when you later try to make sense of all your video files. You can attach markers to the clap as a backup if something goes wrong with the time code. Every time you start a motion capture measurement, you hold the clap in front of the camera an clap.
- Put in batteries
- Find the small ON switch
- Connect with special cable and probably extension cord to XLR output of the word clock (AES1)
- The time code is only displayed when the clap is open
- No one ever tested if you can use this as a remote for Qualisys

Calibration (p. 121 QTM User Manual!)
- Place the L bracket to where you want the origin to be (it will be at the kink)
- If using a force plate, place the L-Shape on the plate to align axes
- You have to wave around the 300mm wand everywhere in the volume you want to measure. Try one axis at a time.
- After the calibration time ends, Qualisys will tell you if the calibration passed. The quality of the calibration is good if the cameras detected a roughly equal number of points and if the standard deviation is low. The current CIRMMT all time MoCap calibration record is as low as 0.32mm (Carolina, 2013).

Software

Cameras
- Adjust reflection level
- Adjust maker threshold
- Adjust exposure
- Marker 240 frame/sec

Calibration:
- Use wand 300, 2 mm

Processing
- To avoid QTM crashes:
  - Real-time: unselect *track each frame in 3D* and *calculate force data*
  - External hardware using Oqus sync and time clock for synchronization
- In many cases, you can lower the *Default Prediction Error* to 25mm and the *Maximum Residual* 5mm. The Default Prediction Error has to be lower than the distance between the two closest markers divided by two in order to prevent marker

Fig. A.4 Page 4 of the Motion Capture Protocol.

trajectory swaps. The Maximum Residual acts like a camera 3D point recognition tolerance and its unit is mm of sphere diameter.

Timing:
- Advanced setting: Master Camera use SMPTE (the Master Camera is the one that has a „M“ on its display)
- Use word clock and SMPTE signals as camera frequency (data are easier to capture to other systems)

Analog board when using force plate:
- Use external sync
- Bipolar -10/10 V
- Video 25 frame/sec
- Marker 240 frame/sec
- Use advances synchro:
  - Master multiplier x1, Use SMPTE
  - Slaves shutter out
- SMPTE = 25 Hz
- Frequency tolerance in PPM of period time = 1000
- Frequency division = 200 (because 240 * 200 = 48,000 : audio sample rate)

Force data
- USB 2533 channels 1-6 Gain 100
- Calibration : (length = 600mm; width = 400mm; height = 50mm; matrix = 2500-2500-5000-1500-1000-750)
- Location:
  - Place markers on top of each corner;
  - Make 1 sec motion capture;
  - Identify the markers;
  - On the force plate page click on generate;
  - Select the marker labels of the current measurement that correspond to each of the corner of the force plate

Use 6DOF rigid bodies
- 6DOF rigid bodies are defined by a fixed set of markers, placed on a static object such as a violin. Once acquired by the system, 6DOF bodies will be recognized whenever they are in the measurement volume, even in real time. The x, y and z position as well as the inclination is calculated.
- Prepare your object with markers. You need at least three markers, four or five are better. Place the markers at positions that are always visible to the cameras. Try to place the markers asymmetrically: Qualisys uses the distances between the markers to calculate the body. As a consequence, symmetry causing equal distances can lead to a situation where the system mistakes one marker for another.
- The QTM User Manual states that the rigid body cannot be flat. Actually it still works pretty fine with plane surfaces.

Fig. A.5 Page 5 of the Motion Capture Protocol.

- A 6DOF rigid body is acquired by placing it into the measurement volume, opening a new measurement and going to Project Settings > 6DOF > Click on Acquire Body button. A body can also be acquired by providing the coordinate manually or by selecting it in an existing motion capture measurement (.qtm) file.

Use AIM models
- If you have one or multiple subjects that repeat the same task, an AIM model (Automatic Identification of Markers) can speed up your workflow. It is basically a machine learning algorithm that compares existing labelled measurements to unlabelled one, trying to figure out the labelling for you.
  - If you completed the labelling of a measurement, go to AIM > Create AIM model
  - Open up a measurement of a similar task. Click AIM > Apply AIM model
  - It probably won't get everything right. Correct it!
  - When everything is corrected, click AIM > Add to existing model
- AIM models learn with every correctly labelled file you add to the model
- You can adjust the relative size of the task in percent. This comes in handy when you are working with adults and children, performing the same task while having different gesture sizes.

Labelling workflow
- Manual labelling can be a tedious exercise. Here are some tips to make your life easier:
  - Use shortcuts! Selecting an unidentified marker and pressing **l** adds a new label.
  - Use unique identifiers such as RH1U (for right hand first finger upper marker), refer to Plug-In-Gait marker placement names where possible!
  - Connect markers with bones to not get confused: Shift-click one marker, then the second one, press **b**.
  - When you labeled all your markers, right click on the labelled trajectories window and save the label list to use it in other .qtm files.
  - Scrub through the measurement and label markers quickly: With a loaded label list, select the first label and **Control-Alt-Click** the corresponding marker. The marker will be associated with the label and the next label will be selected.
  - Want to identify a marker with the context menu > Identify feature, but the marker is not selectable for identification? It's because a part of the marker's trajectory was already assigned to another marker. Try finding the faulty assignment by scrubbing slowly or using the unidentified trajectory list.
  - Some unidentified trajectories left? Select them one-by-one in the unidentified trajectories window and press **c** to center on time and place of the first occurrence.
  - You can drag and drop unidentified markers to a label.
  - Discard wrong measurements of markers and reflection ghost markers by selecting them and pressing **d**.
  - Make use of the sorting features „Fill“ and „Range“ when navigating lists of unidentified markers.

Appendix B

Sight-Reading Materials

This Appendix contains the complete sight-reading score found in chapter 4, as well as the REB-II ethics certification obtained from the McGill Ethics Committee.

Fig. B.1 This figure is the entire sight-reading score which was used for the experimentation in chapter 4 The score is original and was developed by Benjamin Bacon using the Sibelius 6 notation suite for Mac OSX.

Fig. B.2 This is an annotated version of the sight-reading score found in chapter 4. Structural changes and examples of notation in relation to rhythmic function are highlighted.

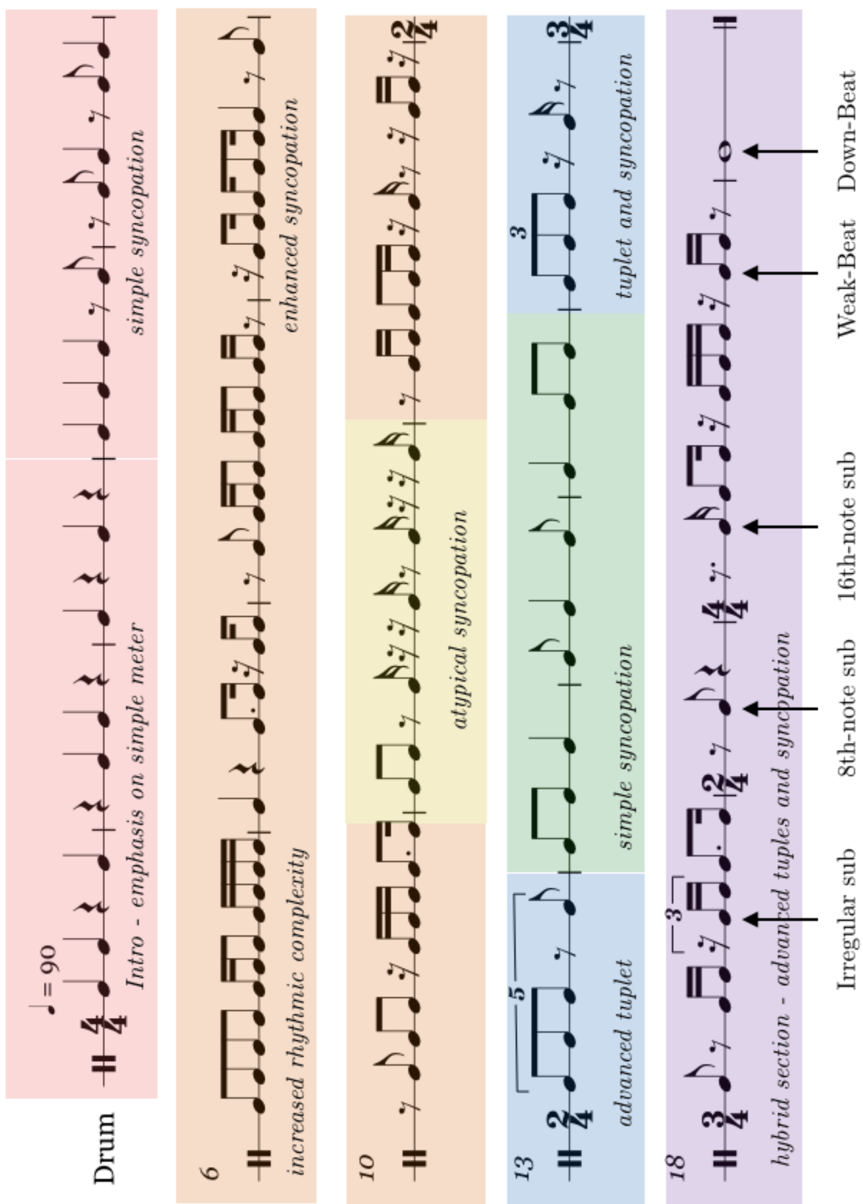


Fig. B.3 REB-II ethics approval from the McGill Ethics Committee for the handedness in percussion performance experimentation.

McGill

Research Ethics Board Office
James Administration Bldg.
845 Sherbrooke Street West. Rm 429
Montreal, QC H3A 0G4

Tel: (514) 398-6831
Fax: (514) 398-4644
Website: www.mcgill.ca/research/researchers/compliance/human/

Research Ethics Board II
Certificate of Ethical Acceptability of Research Involving Humans

REB File #: 139-0913

Project Title: Handedness in percussion performance

Principal Investigator: Benjamin Bacon

Department: Schulich School of Music

Status: Master's Student

Supervisor: Prof. M. Wanderley

Approval Period: **Oct. 01, 2013 to Sep. 30, 2014**

The REB-II reviewed and approved this project by delegated review in accordance with the requirements of the McGill University Policy on the Ethical Conduct of Research Involving Human Participants and the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans.

Deanna Collin
Research Ethics Administrator

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* All research involving human participants requires review on an annual basis. A Request for Renewal form should be submitted 2-3 weeks before the above expiry date.
* When a project has been completed or terminated a Study Closure form must be submitted.
* Should any modification or other unanticipated development occur before the next required review, the REB must be informed and any modification can't be initiated until approval is received.

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