Handedness in Percussion Performance

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Abstract

Percussion's need for accurate, symmetrical movements between hands make it uniquely apropos to the study of handedness in music. Past research has identified both kinematic and functional differences between the hands when playing percussion. Kinematic differences refer to the trajectory of each arm and mallet, while functional differences concern the use of each hand within a musical context. By conducting a two-part motion capture experiment, this work seeks to confirm past results as well as investigate new topics regarding the effects of handedness in percussion performance.

This thesis first focuses on functional differences by characterizing patterns in hand use in right-handed and left-handed players by observing percussionists' stickings during a sight-reading and rehearsed performance of a specially designed musical excerpt. We confirm prior results by observing all participants beginning the exercises with their dominant hand. We further investigate the effects of handedness on sticking strategy and note that the strong preference for the dominant hand in the right-handed group, indicated by both handedness score and reported dominant hand during percussion performance, is clearly illustrated in the group's sticking strategy. All five right-handed percussionists performed using a similar strategy that relied heavily on their right hands, known as right-hand lead. Contrastingly, left-handed players showed no such agreement, using various strategies. This aligns with the left-handed group's less extreme preference for their dominant hand as shown by their handedness scores and reported lead hand. Systematic differences between sticking strategies used in the sight-reading and rehearsed performance indicate a combination of training and handedness affect sticking strategy.

An investigation of kinematic differences follows that includes differences created by musical articulation as well as handedness. Percussion is often seen as much as heard, so it is not surprising that different articulations are created by gestures that mimic the nature of the sound. Measurable differences between stroke types have been observed in past research and is observed in our data as well. By extracting salient quantities from each stroke (preparatory height and striking velocity), we are able to demonstrate clear differences between articulations within each percussionist. By normalizing the data, clearer patterns between percussionists emerge. These measures are then

used to identify the degree of difference between hands for each percussionist. We note that information from only the z axis, preparatory height and striking velocity, is sufficient to discriminate between articulations but is not sufficient to observe systematic differences between hands.

Résumé

La pratique de la percussion, en ce qu'elle requiert des mouvements à la fois précis et symétriques des deux mains, est un champ d'étude adéquat pour les recherches sur la latéralité en musique. Des recherches antérieures ont montré qu'il existe des différences à la fois cinématiques et fonctionnelles entre les mains lors du jeu d'instruments à percussion. Les différences cinématiques correspondent à la trajectoire de chaque bras et de chaque baguette, tandis que les différences fonctionnelles sont liées à l'usage de chaque main en fonction du contexte musical. En réalisant une étude expérimentale de capture du mouvement en deux phases, la présente recherche vise à confirmer les résultats antérieurs - tout en explorant de nouveaux aspects liés aux effets de la latéralité dans le jeu de la percussion.

Cette thèse se penche tout d'abord sur les différence fonctionnelles en caractérisant les modes d'utilisation des mains chez les musiciens droitiers ou gauchers, en observant les doigtés que ceux-ci utilisent durant le déchiffrage et l'exécution préparée d'un extrait musical préparé spécifiquement. Nous confirmons les résultats antérieurs selon lesquels les participants commencent tous avec leur main dominante. Des recherches plus approfondies permettent de noter que la forte préférence pour la main dominante dans le groupe de droitiers, qui apparaît à la fois dans le score de latéralité et la déclaration des musiciens quant à leur main préférée durant le jeu, est parfaitement illustrée par les types de doigtés employés par ce groupe. Les cinq percussionnistes droitiers ont ainsi joué en ayant recours à la même stratégie qui s'appuie essentiellement sur leur main droite, selon la technique connue sous le nom de 'right hand lead'. En revanche, les résultats des musiciens gauchers ne sont pas aussi uniformes, ces derniers utilisant diverses stratégies. Ceci correspond à une préférence moins marquée dans ce groupe pour la main dominante, tant dans les scores de latéralité que dans les déclarations des musiciens sur la main de préférence. Par ailleurs, on note des différences systématiques entre le déchiffrage et l'exécution préparée, ce qui indique que les stratégies de choix de doigtés sont affectées à la fois par la latéralité et par l'apprentissage.

L'étude des différences cinématiques se penche ensuite sur les différences créées par les articulations musicales ainsi que sur les effets de la latéralité. Le jeu de la percussion comporte un aspect visuel autant qu'un aspect sonore, et il n'est pas surprenant de constater que différentes

articulations sont causées par des gestes qui imitent la nature du son produit. Les recherches antérieures ont pu mesuré des différences entre plusieurs types de frappes, ce que confirment nos données. En extrayant les données les plus pertinentes pour chaque type de frappe (hauteur préparatoire et vélocité de la frappe), nous pouvons démontrer des différences claires entre les types de frappe, pour chaque percussionniste. En normalisant les données, des modèles plus différenciés apparaissent entre les percussionnistes. Ces mesures sont ensuite utilisées pour identifier le degré de différence entre les mains de chaque percussionniste. On remarque que les informations provenant de l'axe z, de la hauteur préparatoire et de la vélocité de la frappe sont suffisantes pour distinguer les différentes articulations, mais sont insuffisantes pour observer des différences systématiques entre les mains.

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Contribution of Authors

All images and plots were either created by the author or are attributed in the corresponding caption.

The excerpt used in for the sight-reading and rehearsed performance in Chapter 3 was created by Benjamin Bacon for his Master's thesis (Bacon, 2014). In addition, the raw data from his experiment was re-analyzed using the present methodology in order to validate the current results.

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Chapter 1

Introduction

This chapter serves as an introduction to and general overview of the topics that will be further developed throughout this thesis. Discussions of handedness as well as percussion provide context for the experiments and results reported here.

1.1 The Right and Left

Throughout history, humans have dichotomized the world around them. The concept of opposites simplifies decision making processes from a complex gradient to a single choice: yes or no, black or white, wrong or right. Duality is common in philosophies from around the globe. Aristotle's table of Ten Opposites (Hall 2008) is shown in Table 1.1. Since the grouping and choice of opposites is entirely subjective, the table offers a glance into the philosophy of the time.

Given Aristotle's importance in Western philosophy, his grouping of *Right* with *Good* and *Light* suggests an influential bias toward the right side. However, there is nothing inherently *Bad* or *Dark* about the left side of the body.

The Chinese concept of Yin-Yang is less disparaging toward the left, as both yin and yang are equally necessary for a harmonious existence. However, the right side's relationship with yang and all things light, bright, and warm show a similarly ingrained bias toward the right side (Osgood and Richards 1973). These social biases toward the right side stem from a clear physiological bias

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

in the human body.

Approximately 88% of the population is right handed (Annett 1996; Raymond and Pontier 2004; Treffner 1995). Most other animals show little preference for one hand or paw over the other. However, our closest evolutionary relatives, bonobos and chimpanzees, do exhibit population-wide right handedness (Hopkins 2006). It is hypothesized that human lateralization is related to the evolution of language (Beaton 1997; Geschwind and Levitsky 1968; Toga and Thompson 2003), but the neurobiological basis of handedness is outside the scope of the current work.

Regardless of cause, this bias towards right handedness existed in early humans as well (Frayer et al. 2010). Regardless of geographic, cultural, or historical borders, handedness appears across the globe, with people identifying as either right or left handed (Corballis 1983). While the right side is preferred by the majority of the population, there are very few individuals that use the same hand for every task. In fact, a continuum of handedness exists between completely left handed and completely right handed (Annett 1970). This continuum and the human bias toward the right side will be discussed in more detail in Chapter 2.

1.2 Percussion

Given the bimanual nature of percussion performance, it is particularly relevant to the study of laterality in a musical context. Many instruments require the use of both hands in concert, but percussion is unique in its need for parity of movement and sound between hands.

The basics of percussion are seemingly straightforward. Using either a stick or hand, a percussionist strikes an instrument to set it vibrating. Given its simplicity, the definition of a percussion instrument is the loosest among instruments. In fact, the transition from normal object to percussion instrument is sometimes as simple as having a player willing to hit it (See Section 2.2 for further discussion). Alongside the classic orchestral instruments like the timpani and triangle, tin cans, rocks, or even the stage itself are all equally valid. This flexibility in instrumentation requires the percussionist to adapt their playing gesture to each instrument, set of instruments, or piece of music. It is this simplicity that attracted early musicians to percussion, making it one of the earliest instrument families (Hart, Stevens, and Lieberman 1998).

While the act of playing percussion appears elementary, the interaction between player and instrument is no less complex than any other instrument. Different striking surfaces and mallets require players to adjust their playing gesture to affect their musical intention within the physical constraints imposed by the particular instrument (Dahl 2000). The diverse needs of percussion have given rise to thousands of types of mallets and many grip techniques.

Despite the variety present in percussion, one thing remains consistent: the importance of rhythm. Due to the limited pitch options available for many percussion instruments and the rhythmic role of percussion in many types of music, players have developed an extremely acute sense of time. Research concerning this phenomenon will be discussed in further detail in Chapter 2.

1.3 Research Motivation and Hypotheses

As a left-handed percussionist, the topics of handedness and percussion are of particular interest to the author. While percussion and handedness are both popular topics of research, the combination has only begun to be explored. The results of Benjamin Bacon's work showed a clear relationship between handedness and percussion performance (Bacon 2014). However, due to the small sample size, only limited conclusions could be drawn.

This thesis expands upon his work by including a larger sample of left-handed players, players of varying skill, as well as a rehearsed performance of the excerpt. In this way, the asymmetries introduced by handedness can be generalized with greater accuracy and also the effects of classical percussion training on these asymmetries can be investigated.

While snare drum is perhaps the quintessential percussion instrument, timpani was chosen for the experiment to be able to directly compare previous work like that of Bacon (2014), Alexandre Bouënard et al. (2008, 2009, 2010), and Lei Chen et al. (2016). The larger gestures required to play timpani ideally allow easier comparison as any differences in gesture are magnified by the greater distance traveled.

The two-part experiment conducted for this thesis was designed to confirm two past results from the literature and test two new hypotheses. These can be grouped into pairs with one past result and one new questions based upon their focus: functional or kinematic differences between the hands.

When discussing functional differences, first and simplest is confirming Bacon's result that percussionists initiate tasks with their dominant hand according to their handedness. Second is that handedness affects the choices a percussionist makes regarding the musical function of each hand while performing. As a corollary to the second hypothesis, we also expect there to be differences between the strategies used in the sight-reading and the rehearsed performance.

We also seek to confirm that articulations can be identified from the mallet trajectory as shown in Bouënard, Wanderley, and Gibet (2010). Finally, past research has shown that the mallet trajectories of each hand are not entirely symmetrical (Bacon 2014; Dahl and Altenmüller 2008), so we hypothesize that we will also see systematic differences in the trajectories between hands, and that these differences will be related to handedness.

1.4 Thesis Structure

To properly contextualize this research within the literature as well as link the major elements of this work (percussion pedagogy, handedness, and gesture analysis), the chapters of this thesis will be as follows:

1.4.1 Chapter 2 - Handedness and Percussion

This chapter presents the most relevant findings in the fields of laterality and music as well as provides an overview of percussion instruments, grips, and pedagogy. Handedness research and percussion are initially treated separately and are then combined to lay the theoretical groundwork for the results discussed in later chapters.

1.4.2 Chapter 3 – Effects of Handedness on Performance Strategy

Past research identified relationships between hand use during percussion performance and handedness (Bacon 2014). In this chapter, we repeat the sight-reading experiment conducted by Bacon (2014) and include a rehearsed performance of the same excerpt. This section will deal with the first pair of hypotheses concerned with functional differenes between the hands. By comparing the sticking strategy used in each performance, we will be able to identify patterns in hand use caused by handedness. Furthermore, by comparing the rehearsed performance to the sight-reading, we will be able to observe the effects of training on sticking strategy.

1.4.3 Chapter 4 – Effects of Handedness on Performance Kinematics

The playing gesture will be the main focus of this chapter. By measuring the mallet trajectory while percussionists perform a bimanual, symmetrical task, we will be able to establish patterns in mallet movement between percussionists of differing expertise as well as handedness. By comparing the trajectories of each hand, we can observe the degree of symmetry between the playing gestures of each hand. Though symmetry of motion is essential in percussion, the degree to which handedness affects this symmetry has not been thoroughly studied.

1.4.4 Chapter 5 – Conclusion

This section reiterates the results of Chapters 3 and 4 by covering each hypothesis independently. It also provides suggestions for improvement and paths for future work.

Chapter 2

Handedness and Percussion

This section outlines the most salient methods and findings within the field of handedness research as well as a discussion of percussion instruments, grips, and pedagogy to provide a context for the experimental results described in later chapters.

2.1 Handedness

When considering handedness, people generally identify as right-handed or left-handed based on which hand they prefer to use to write. With between 85% to 90% of the population identifying as right-handed (Perelle and Ehrman 1994; Raymond and Pontier 2004; Treffner 1995), humans are unique among animals in degree of handedness. When measuring handedness, two different values have been commonly measured: *hand preference* and *hand performance*.

In the past, *hand preference* was equated with handedness and was measured using questionnaires like the Edinburgh Handedness Inventory (Oldfield 1971). More recently, *hand performance* has been used with increasing prevalence due to its more objective quality to verify or in place of *hand preference* (Kopiez, Galley, and Lehmann 2010; Nicholls et al. 2010). However, recommended practice is to record a value for both (Ocklenburg, Beste, and Arning 2014). The common methods and the different distributions that commonly result from both measures of *hand preference* and *hand performance* will be discussed in this section.

2.1.1 Measuring Handedness: Hand Preference

Most people prefer to use one hand or the other for a particular task. However, *hand preference* exploits the fact that few individuals prefer the same hand for all tasks. In fact, by noting which hand is used for common tasks like writing, throwing, and eating, an individual's degree of handedness can be measured (Annett 1970; Oldfield 1971). This transforms the often dichotomous view of handedness into a continuous distribution. However, unlike other animals, the distribution is not symmetrical about ambidexterity, but weighted towards right-handedness (Annett 1998).

In this section, two experiments will be discussed that helped cement the idea of handedness as a continuum through the measure of *hand preference*. The results of both experiments identified the hand used for writing as a strong indicator of handedness, so it is not surprising that this is the task most associated with identifying handedness in modern societies. However, using only a single task removes information about the degrees of handedness that exist.

Since their introduction in the early 1970's, two questionnaires have dominated the field for measuring *hand preference* (Dragovic and Hammond 2007; Milenkovic and Dragovic 2013; Williams 1991). While both ask participants to note which hand they prefer to use for a number of tasks, the recording method and analysis for each are slightly different.

Annett Handedness Questionnaire In her questionnaire, Marian Annett asked participants to indicate their preferred hand for 12 tasks (e.g. writing, throwing, striking a match, etc.) as either 'right', 'left', or 'either'. She collected over 2,000 responses from undergraduates at the University of Hull. Using association analysis, she was able to identify several activities that were stronger indicators of handedness (writing, throwing a ball) than others (unscrewing a jar) (Annett 1970).

Edinburgh Handedness Inventory Around the same time, R.C. Oldfield conducted a similar experiment at the University of Edinburgh with about 1,100 participants involving a handedness questionnaire of his own design. The survey began with 20 items but was reduced to 10 due to highly correlated scores between various similar activities like using a cricket bat or golf club (Oldfield 1971). By removing extraneous items, it was hypothesized that the accuracy of the scores increased without the biases created by items that were too similar.

Unlike Annett, instead of simply marking which hand was preferred for each task, Oldfield had subjects indicate the degree of preference in each task with +'s. Two +'s in a box meant that the subject would never use the opposing hand. A single + indicated slight preference, while one in both the right and left box indicated no preference. Once completed, a laterality quotient (LQ) or handedness score was computed using the following equation:

$$LQ = 100 \times \frac{(R - L)}{(R + L)} \tag{2.1}$$

where R corresponds to the number of +'s in the right column and L the number in the left column, respectively. With scores ranging from -100 (strongest left preference) to $+100$ (strongest right preference), Oldfield gained a more quantitative representation of a subject's degree of handedness. While seemingly more quantitative, computing the handedness score in this way assumes that all activities should be given equal weight. As a result, the distribution of scores was J shaped with a high number of strongly right-handed individuals, some strongly left-handed, and few between (Oldfield 1971). A similar distribution can be seen in the current results and will be discussed more in the next chapter.

2.1.2 Measuring Handedness: Hand Performance

Hand performance quantitatively measures each hand on the same task to allow direct comparison. Unlike *hand preference*, *hand performance* tends to follow a roughly normal distribution that is shifted to the right (Annett 1985; Nicholls et al. 2010), due to the majority of the population preferring their right hand. This phenomena was deemed the *right shift* by Marian Annett, who extended the idea into the Right Shift Theory in several books (Annett 1998, 2013). While using a handedness questionnaire allows for a quasi-quantitative measure of handedness, task-based methods have become the norm as a more accurate quantitative measure of handedness. Task-based methods allow more objective measures of hand skill asymmetry and therefore have become accepted as a better indicator of handedness than inventories alone. Several different tasks have been used to measure hand skill asymmetry.

Pegboard Task The pegboard task has often been used to measure differences between hands (Annett et al. 1979; Annett 1985; Scerri et al. 2011). The task involves moving 10 pegs from one set of vertical holes to another on the other side of the board using one hand. The activity is timed for each hand and the difference is used as a measure of hand skill asymmetry. It has been shown that the non-dominant hand takes longer not because of slower movement when moving the pegs across the board but due to an increased number of small corrective adjustments made at the end of the motion (Annett et al. 1979). Compensating for the lack of precision exhibited by the non-dominant hand in this work could be related to the tenet in percussion pedagogy urging students to spend extra time improving their non-dominant hand (Delecluse 1969; McClaren 1994).

Tapping Tasks Tapping tasks are one of the most oft used measurements when identifying the effects of handedness, musical training, and other factors in humans (Repp 2005). Comparing the number of taps provided by each hand in a particular time frame is a popular method for measuring a person's degree of handedness (Kopiez, Galley, and Lehmann 2010; Peters 1980, 1981; Peters and Durding 1978).

Michael Peters helped standardize and popularize the experimental methods linking tapping speed to handedness. By measuring the number of taps made by each hand over several trials of 10 seconds, he showed that the tapping motion of the dominant hand was more efficient, due to the increased muscle control in the dominant hand (Peters 1980), similar to the pegboard test results (Annett et al. 1979; Annett 1985; Scerri et al. 2011). Peters also investigated the effects of training on hand skill asymmetry. As participants grew more adept at tapping, the speed increased at about the same rate for each hand, while leaving the initial discrepancy between hands intact (Peters 1981).

In Peters' work, lateralization coefficients were calculated using a similar formula as with the Edinburgh Handedness Inventory. Instead of using the number of items in the right and left column of a questionnaire, the difference in values like number of taps or average inter-tap interval between hands provided a more objective measure of the participants' degree of handedness (Peters and Durding 1978). Kopiez et al. (Kopiez, Galley, and Lehmann 2010) utilized a similar paradigm in order to define a statistical classification of handedness. By measuring the number of taps, regularity (spread of inter-tap interval distribution), and fatigue (difference between medians of taps in the first and last five seconds) Kopiez et al. were able to more accurately place participants along the continuum of handedness.

2.1.3 Handedness in Music

Given the bimanual nature of most instruments, it may not be surprising that musicians tend to have a smaller gap in hand skill than non-musicians. Using both hands in concert as part of their musical training appears to increase the skill of musicians' non-dominant hand relative to their dominant hand (Jäncke, Schlaug, and Steinmetz 1997). However, other research suggests that the bimanual nature of many instruments merely increases the skill of both hands, while leaving the gap between intact (Kopiez, Galley, and Lehmann 2010). While it is clear that musical training improves hand skill, it is still unclear if the effects are from repetition or related to a critical learning window, similar to language.

2.2 Percussion

Percussion, at its most basic, possesses a deceptively simple definition: one only requires something to strike and something with which to strike. However, this belies the complex interaction between player and instrument and how percussionists must adjust their playing strategy to different playing surfaces (Dahl 2004) and instruments (Cook 1997; McClaren 1994; McCormick 1983). Regardless of the instrument, percussion pedagogy emphasizes the need for an even sound between hands (Cook 1997; Delecluse 1969), through careful attention to the sound and minimizing discrepancies between the playing gesture of each hand.

While anything could be considered a percussion instrument if played in a musical context (even a cactus, as in John Cage's *Child of Tree* (Cage 1975)), percussion is generally divided into two families of instruments: pitched and unpitched. The following discussion focuses primarily on drums, members of the unpitched instrument family. It is worth noting that timpani are usually tuned to particular pitches during performance. However, the drum itself and the mechanics of playing timpani is much more similar to that of snare drum or tom tom, instruments where pitch is not generally considered important, than the xylophone or marimba, which are traditionally placed in the pitched instrument family. To incorporate the ideas of laterality, drums have been further divided into groups of symmetrical, single instruments and asymmetrical groups of drums.

2.2.1 Symmetrical Instruments

Single, round drums are by nature symmetrical. Instruments like the snare drum, tom-tom, or a single timpani belong to this group (Figure 2.1). Due to their construction, they are not biased toward one hand or the other during playing. However, this does not preclude percussion performance from the effects of human laterality.

Snare Drum: Traditional vs. Matched Grip Snare drum in particular has historically been the instrument on which a percussion learns and hones their technique (Cook 1997; McCormick 1983). The snare drum's use as a military instrument required a playing strategy that would be comfortable while marching. Since the majority of people are right-handed, having the drum-head tilted toward the right would keep it out of the way of the player's knees while allowing the dominant hand to hold a stick comfortably (Blades 1992). However, the tilt in the drum made a standard overhand grip uncomfortable for the left hand. To solve this issue, drummers adopted 'traditional grip', in which the right hand holds a stick overhand, while the left hand plays underhand (Figure 2.2) (Delecluse 1969; Stone 1935). By inverting the left hand, drummers could play comfortably and keep the drum out of the way of their legs while marching (Blades 1992;

(a) (b)

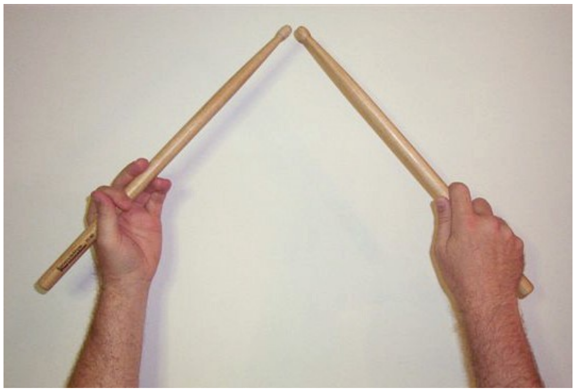
Fig. 2.1 Snare Drum and Timpani
Top view of a (a) snare drum (36 cm diameter) and a (b) timpani drum (58cm diameter). The playing surfaces are circularly symmetrical, so there is no inherent bias toward a particular hand when performing. *image credit*: Benjamin Bacon

Mattingly 2002).

Since drums were used to give battle instructions to soldiers during combat, as battlefield strategies shifted away from marching formations, it was no longer necessary for drummers to be able to march while playing. In response, during the latter part of the 20th century, percussion pedagogy shifted away from military drumming and toward a grip that allowed greater flexibility (Cook 1997).

This shift can be observed not only in orchestral percussionists but also in the grips used by drum set players. With the advent of jazz in the early 20th century, many drummers utilized traditional grip while playing due to their military influences (Brown 1976). Rock and roll drummers tended to use matched grip, although several notable exceptions, like Ginger Baker of *Cream*, preferred traditional (Palmer 1977a,b).

Matched grip came to replace traditional grip as the standard in percussion pedagogy partly due to its transferability between instruments. While traditional grip is only useful for snare



(a)

(b)

Fig. 2.2 Traditional Grip
(a) Top view of traditonal grip and (b) a close up of the left-hand grip. *image credit*: Brad Halls

drum, a beginning percussionist that learns matched grip can quickly learn to play timpani and even pitched instruments like marimba with only minor adjustments to the playing strategy (Cook 1997).

(a)

(b)

Fig. 2.3 Matched Grip
(a) Matched grip and (b) view of finger position from the underside

The matched grip, shown in Figure 2.3 , has both hands hold a stick in the same way, referred to as overhand. With the top of the hand facing up, the forefinger and thumb act as a fulcrum as the wrist and arm raise and lower the stick. The middle, third, and pinky fingers are used to finely adjust the range of motion of the stick during the strike and rebound (Delecluse 1969; McCormick

1983)(Figure 2.3b). The same motion is used for both timpani and pitched instruments with special mallets instead of the drum sticks used for the snare drum.

Timpani: German, French, and American Grip Similar to snare drum, timpani, also called kettledrums, originated as military instruments in the Middle East (Blades 1992). However, their large size often necessitated that they be played while mounted on a horse or camel (Encyclopædia Britannica 2014). Since comfort while marching was not an issue, matched grip was the preferred grip when playing timpani and continued as the standard as timpani transitioned from military to orchestral instruments.

Within the family of matched grips, two different styles are most commonly used when performing on timpani: German and French. The origin of the terms is unclear, but likely reference differences between the Viennese and French styles (Kruse-Regnard 2003) passed down from timpani instructor to student through oral tradition. While the two grips are considered pedagogically distinct, few percussionists use one or the other exclusively. Far more important for timpanists is the ability to adjust the hands in order to create different musical effects rather than strictly conforming to a single technique (Reifel 2011). While it is uncommon to use both grips simultaneously, elements of each are utilized by many percussionists, with the combination of the two referred to as American Grip (Cook 1997).

(a) (b) (c)

Fig. 2.4 Common Timpani Grip Examples
(a) German (b) French (c) American

German Grip is very similar to the matched grip used for snare drum (Figure 2.4a): the palm faces downward and the wrist and arm move the stick while it pivots between the thumb and forefinger (Cook 1997; Peters 1993). The motion during playing is mostly vertical and from the wrist, with the action being similar to knocking on a door (Cook 1997; Peters 1993). This gesture makes it easier to perform sharp, staccato strokes (Berkowitz 2011).

In contrast, French Grip (Figure 2.4b) has the palms facing inward while the thumbs are placed on top of the mallets (Cook 1997; Peters 1993). This creates a greater range of motion of the mallet compared to German grip (Bouënard, Wanderley, and Gibet 2010). Instead of a knocking motion, French grip employs a loose wrist similar to casting a fishing line (Cook 1997; Peters 1993).

As mentioned previously, American Grip is a hybrid between the French and German grips. As can be seen in Figure 2.4c, the palms are neither parallel nor perpendicular to the floor but at approximately a 45 degree angle. This allows users of American Grip a great deal of flexibility during playing (Peters 1993). However, American grip lacks the extremes in power and range of motion provided by German and French grip, respectively.

2.2.2 Asymmetrical Instruments

By arranging multiple drums of various pitches together into a single set, percussionists are able to increase the melodic and timbral possibilities with minimal effort. For example, the modern drum set gives drummers access to many timbres to highlight and support the band. However, the increase in possibilities introduces functional asymmetries.

The standard drum set arrangement is ideal for right-handed players. The bass drum is played with the right foot, the right hand anchors the beat by playing rhythms on the hi-hat or cymbals, while the left hand fills in on the snare drum. The standard arrangement of the instruments, while beneficial for right-handed players, can be awkward for left-handed players. However, due to the effort required to physically rearrange a drum set, many left-handed players adjust their playing strategies to a standard drum set instead of vice versa (HBO 2008).

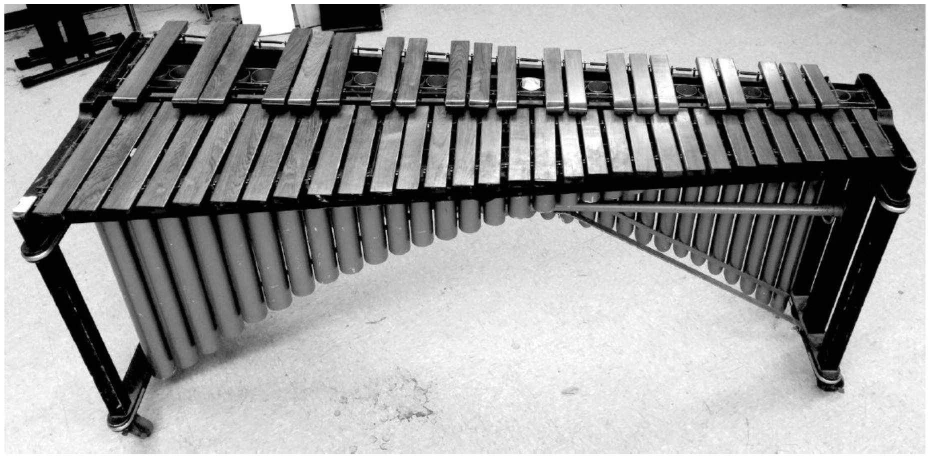


Fig. 2.5 Standard 4.3-octave marimba
Because of the physics involved, bars must descrease in size as they increase in pitch. This leads to greater asymmetry between the right and left side than the piano, which has equally-sized keys throughout. *image credit*: Benjamin Bacon

Pitched instruments like marimba and xylophone also introduce asymmetries when performing. Similar to a piano keyboard, notes increase in pitch from left to right (Figure 2.5) and require percussionists to generally play notes in the low register with the left hand and higher notes with the right hand. Futhermore, lower notes are larger than higher notes due to the physics of the instrument. While single drums could theoretically be played without concern for laterality, this is simply not true for keyboard percussion.

2.2.3 Sticking Strategies

After the percussionist sets the instrument vibrating, they have little control over the sound. For this reason, the kinematics of the stroke define the acoustic properties of each note (McCormick 1983; Stone 1935). Symmetrical gesture between hands helps ensure an even sound when alternating hands during performance (Cook 1997). To counteract their natural asymmetry, a central tenet of percussion pedagogy prescribes that students spend extra time practicing to bring their non-dominant hand up to the skill level of their dominant hand. In fact, a ratio of 3:1 is recommended by top pedagogues (Delecluse 1969; McCormick 1983). To help foster parity during training, method books provide systematic stickings for each exercise that emphasize each hand in turn (Delecluse 1969; Goodman 2000; Gworek 2017; McCormick 1983; Stone 1935).

While symmetry is an important goal for percussionists, it is not always necessary or even preferable. Slight differences between the hands can be used to add musicality to rhythms. Some players use sticking strategies to highlight note groupings within a musical phrase. For example, a right-handed player could use a R L R L L sticking to indicate a grouping of 2 and 3 within a measure to better align with the melodic structure. Because many percussion instruments have only a single pitch, players must find alternative ways to play musically, using each hand for unique musical functions (Bacon 2014). Hand use as it relates to musical function is the topic of the next section.

Right/Left-hand Lead Given the importance placed on symmetry of gesture in percussion, it would not be surprising for there to be little preference for a particular hand to play a certain type of note. However, the functional roles of the hands are often distinct (Bacon, Wanderley, and Marandola 2014). Throughout the history of percussion, players learned that performance often improved when relying on the dominant hand for metrically important notes within a piece of music (McCormick 1983): the dominant hand acts as an anchor while the other hand 'fills in'. This playing paradigm has become known as 'right-hand lead' for right-handed percussionists and 'left-hand lead' for left-handed players (McClaren 1994; Stone 1935). Using this system, each rhythm is played the same way every time, providing more consistency during performance (Mattingly 2002). The non-dominant hand performs better when automated (Peters 1986), so by focusing attention on their dominant hand, percussionists maximize their rhythmic accuracy and sound quality. For this reason, right/left-hand lead is the most popular sticking strategy for professional percussionists (McCormick 1983). Despite its prevalence, right/left-hand lead is not the only sticking strategy utilized by percussionists.

Hand to hand/Alternating Hand to hand or alternating sticking is also commonly utilized in conjunction with or in place of right/left-hand lead (McCormick 1983). Instead of using the dominant hand to anchor, each hand is used equally. Certain schools of pedagogy strongly advocate for alternate sticking. Since the goal is to match the gesture of each hand as closely as possible, there should be no reason for functional differences between hands. While perhaps true in theory, preference for one hand is not entirely absent in practice, since the dominant hand will usually initiate each rhythmic section when performing (Bacon 2014).

2.2.4 Timing

Past research has shown that musicians have better beat perception and rhythmic production than non-musicians (Drake 1993; Drake, Penel, and Bigand 2000). Due to the rhythmic focus of percussion training, it would be expected that among musicians, percussionists in particular would possess enhanced rhythmic abilities. For percussionists, amount of musical training directly correlates to increased tapping speed as well as decreased hand skill asymmetry, when measured by unimanual tapping speed with drum sticks (Fujii and Oda 2009). In addition, it has been shown that percussionists have superior tapping speed and consistency compared to non-percussionists (Fujii et al. 2010). Percussionists also possess improved rhythmic production capabilities (Cicchini et al. 2012), sensitivity to rhythmic deviations when allowed to move with the rhythm (Manning and Schutz 2016), and increased awareness of asynchronies between audio and visual stimuli (Petrini, Holt, and Pollick 2010; Petrini et al. 2009) than both non-musicians as well as non-percussionist musicians. This sensitivity to rhythm even extends beyond the bounds of common music; percussionists more accurately recreate rhythms compared to non-percussionists, even if the rhythms are not musically plausible (Cameron and Grahn 2014).

2.2.5 Kinematics

Percussionists are more adept at rhythmic production due to their training. When comparing raw tapping speed, percussionists are able to more efficiently utilize opposing muscle groups in the wrist and arm than non-percussionists, resulting in higher speed and more consistent tapping (Fujii et al. 2009). These benefits are present whether the player taps only with their hands or with a stick (Fujii and Oda 2009). The rebound off the drum head is also an important tool employed by percussionists.

When comparing muscle activity between performing with a drum and with an imaginary drum head, the effort required to play was less when the drum was present (Fujisawa and Miura 2010). Percussionists are required to arrest the stick's momentum when there is no drum present, which greatly increases the energy needed to play. By using the natural rebound of the drum, percussionists are able to perform rapid bimanual rhythms with a high degree of accuracy for an extended period of time.

2.3 Handedness in Percussion

Bacon, Wanderley, and Marandola (2014) conducted their foray into the effects of handedness in percussion through two experiments, a neutral task and sight-reading task, and the use of motion capture (mocap) technology. They were able to demonstrate two major types of differences between the hands and their relation to handedness.

Kinematic differences refer to the trajectory of the mallets and the movements of the arms. The neutral task provided the testing ground for the investigation of the trajectories. The neutral task was comprised of playing 32 strokes on a single timpani using an alternating sticking pattern. Without any complex rhythms or changes in dynamic or tempo, the raw playing gesture could be studied.

The exact location of the mallet was measured using mocap throughout the exercise; using this information, Bacon demonstrated that the mallet of the non-dominant hand has more variability in its trajectory compared to the preferred hand. This is unsurprising given a person's greater motor control over their dominant hand (Annett 1985). This asymmetry in gesture had been previously observed with a neutral task (Dahl and Altenmüller 2008) but the effects of musical context had not been fully explored.

The sight-reading task was designed to test the functional uses of each hand. As previously discussed, there are many different combinations of sticking strategy available to percussionists.

By forcing the players to sight-read, the stickings used would be automatic reactions instead of carefully planned. It was hoped that the reflexive nature of sticking choice during sight-reading would shed light on the influences of handedness on sticking strategy. Percussionists showed a clear correlation between dominant hand use and metrical importance of the note regardless of handedness. However, due to the small number of left-handed players as well nothing to compare the sight-reading data to, the results were limited in scope.

The current work seeks to build upon the work of Bacon to more fully investigate the effects of handedness in percussion performance.

Chapter 3

Effects of Handedness on Performance Strategy

Earlier research concerning handedness in percussion utilized sight-reading to reveal the reflexive sticking strategies of percussionists (Bacon, Wanderley, and Marandola 2014). Unfortunately, due to the cognitive load of sight reading (Kopiez and In Lee 2008), these results could not be simply extrapolated to rehearsed performances. In this chapter, we present the results of a sight-reading task as well as a rehearsed performance of the same excerpt. In this way, we are able to compare the sticking strategies between the two performances. Given the results of Bacon, Wanderley, and Marandola (2014), we hypothesize that percussionists will initiate the exercise with their dominant hands. We also expect to see systematic patterns in hand use during performance. However, whether these patterns are symmetrical for right-handed and left-handed players or if they are player-dependent is yet unclear.

3.1 Musical Score

In order to facilitate direct comparison between the current results and those of past research, the same excerpt from Bacon (2014) was utilized for the current experiment. The score was composed with handedness in mind. It slowly increases in complexity but never becomes so difficult that it could not be performed using an alternating strategy (Bacon, Wanderley, and Marandola 2014). Because no specific sticking is required, percussionists are free to use whatever strategy is most effective for them. This protects against excerpt-dependent sticking strategies. Differences between participants are then more likely explained by differing strategies influenced by the players' training and handedness preference.

Each note in a musical score can be labeled by its metrical value and placement within the measure. For the current analysis, 4 note classes were chosen: downbeats, beats, 8th note syncopations, and 16th note syncopations. Downbeats refer to the first beat of every musical measure. Beats are the largest subdivision of a musical measure and are vital to the measure's structure. Finally, 8th note syncopations fall exactly halfway between each beat while 16th note syncopations are the halfway point between beats and 8th note syncopations (Figure 3.4). Each note of the excerpt can belong to only one of these groups. The irregular subdivisions (5-tuplets and triplets) were not included in the analysis because they could not be consistently placed into one of the four note groups. In addition, it is not clear if placing notes of different metrical values into a single group would introduce any confounding factors. To remove this possiblility, the irregular subdivisions were not included; however, future research should investigate the effects of irregular subdivisions on sticking strategy.

3.2 Methodology

3.2.1 Participants

Participants included 10 percussionists ($M_{\text{age}} = 30.1$, $SD = 8.68$, $range = 20-47$, 5 left-handed). The skill level of the percussionists was high with a minimum of 2 years of university-level training ($M_{\text{training}} = 13.9$, $SD = 4.06$, $range = 7-18$). All percussionists had completed or were pursuing a degree in percussion. Six of the ten had completed a graduate-level degree. Of the remaining, three were pursuing a graduate-level degree, while the final player was completing their undergraduate degree. Table 3.1 shows the demographic data of the participants.

Table 3.1 Demographic Data
Demographic data for the 10 percussionists separated by handedness. The Training column corresponds to the years of training each had received. The Lead column shows the answer to the extra question on the handedness survey regarding preferred hand during performance.

	Handedness Score	Age	Sex	Training	Lead
Left 1	−40	26	M	18	Both
Left 2	−63.6	20	M	7	Both
Left 3	−55.5	24	M	17	Both
Left 4	−63.6	30	M	11	Left
Left 5	−9.1	33	M	18	Left
Right 1	100	45	M	18	Both
Right 2	100	28	F	8	Right
Right 3	69.2	25	F	12	Right
Right 4	100	23	F	13	Right
Right 5	84.6	47	M	18	Right

In order to maximize the number of left-handed players, we advertised specifically for left-handed players when recruiting participants. A 50/50 split, while not representative of the population, allowed us to more thoroughly investigate the usually underrepresented left-handed population.

A handedness score was calculated for each participant using the Edinburgh Handedness Inventory (Oldfield 1971). Scores ranged from −100 (strongest left preference) to +100 (strongest right preference). Results are shown below (Figure 3.1). One extra question concerning preferred hand when playing percussion was added to the survey. The extra question was not included in the handedness score calculation but was instead recorded separately (Table 3.1, Lead).

With scores closer to the extreme value, right-handed participants more strongly preferred their dominant hand than did left-handed participants. The stronger dominant hand preference in right-handed individuals aligns with earlier findings on handedness (Annett 1996; Humphrey 1951).

During the handedness survey, several left-handed participants reported using their left hand for tasks when the option was provided but certain tasks like using scissors necessitated the use

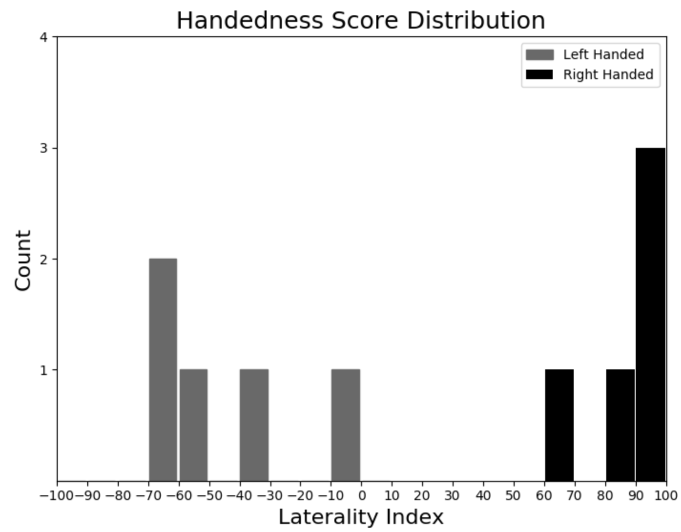


Fig. 3.1 Handedness Score Distribution for All Participants.

Table 3.2 Handedness Score Data
Mean, standard deviation, and range of handedness scores for both handedness groups.

	Mean	Standard Deviation	Range
Left	−46.36	20.53	−63.6 − −9.1
Right	90.76	11.32	+69.2 − +100

of the right hand because of the available tools (i.e. lack of left-handed scissors). This lack of left-handed tools is also present in percussion. While single drums are by nature symmetrical, sets of drums like timpani or drum set as well as keyboard instruments are not. The asymmetry necessitates performing certain notes with a particular hand. For example, drum sets are standardly arranged for right-handed players. Left-handed players, like Ringo Starr, adapted their playing style to accommodate the instrument instead of vice versa (HBO 2008). Because of the bias towards the right side present in society, it is possible that the handedness scores of the left-handed players were artificially shifted to the right. However, the shift possibly created by a single question (scissor use) is not enough to account for the large difference in magnitude of the handedness scores of the right-handed and left-handed groups.

The preference for the dominant hand could also be seen in the responses to the extra question regarding lead hand during percussion performance in the handedness survey (Table 3.1, Lead). Four out of five right-handed player reported using their right hand as the lead hand while only 2 left-handed players reported preferring to lead with their left. Unsurprisingly, no players reported preferring to lead with their non-dominant hand.

Fig. 3.2 Musical Excerpt
Musical excerpt composed by Benjamin Bacon. Rhythms gradually increase in complexity throughout the excerpt.

3.2.2 Design and Procedure

The excerpt (Figure 3.2) was designed to contain rhythms that are representative of standard percussion repertoire and that gradually increase in complexity (Bacon 2014). It was composed such that there are approximately equal numbers of notes that occur on the beat and syncopations, so that direct comparisons could be made regarding hand choice for each note type. Downbeats are limited to one per measure, so it is not surprising that there are so few relative to the other note types. However, nearly equal number of beats and each syncopation type provides us a well-balanced sample.

Table 3.3 Number of Notes per Note Group
The number of notes contained within each note group.

Note Type	Number	Percentage
Downbeats	13	13.6 %
Beats	29	30.2 %
Syncopations	27	28.1 %
16th Syncopations	27	28.1 %

Each percussionist performed the excerpt twice (sight-reading and rehearsed performance). The experiment begin with the sheet music face-down. Each player was asked to flip over the paper and was given only enough time to return to playing position before a metronome signal, four beats at 90 beats per minute. After completing the sight reading, each percussionist was given up to five minutes to practice and reevaluate their playing strategies in order to correct any mistakes or improve the overall quality of the performance to the best of their ability. While percussionists were allowed to tap or sing, they were instructed not to play during this time. No instructions were given regarding sticking strategy for the excerpt. After five minutes, another four beats at 90 beats per minute were provided by the metronome, and each percussionist played the excerpt a second time.

3.2.3 Apparatus

During the experiment, the players were recorded using a Sony PMW-300 video camera with an attached Neuman TLM170R condenser microphone set with a cardioid pattern. All percussionists performed on a 23 inch Adams Professional Gen II Timpani with a pair of David Herbert DH2 fiberglass timpani mallets. Figure 3.3 contains a frame from the video and shows the playing position of participant Right 1.

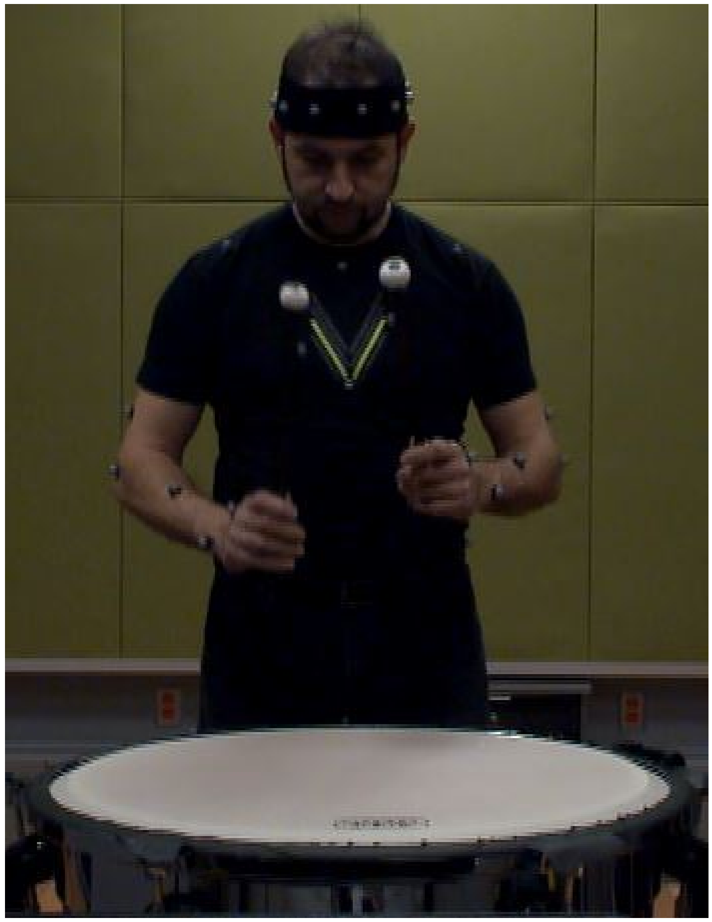
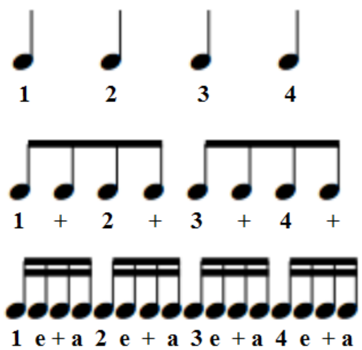


Fig. 3.3 Participant Right 1 Ready Position
Body and mallet preparation immediately before beginning to play.

3.2.4 Analysis

Each note of the excerpt was labeled according to its metrical importance. Downbeats, the first beat of every measure, are the most important, as they delineate musical measures. Beats are the second most important since they are the largest subdivision of each measure. Each beat can be further subdivided into 8th note syncopations and 16th note syncopations, as shown in Figure 3.4a. An example from the excerpt can be seen in Figure 3.4b.

Once each note was labeled, it was placed into one of four groups of decreasing metrical importance. The performance videos were annotated in order to determine which hand each



(a)

(b)

Fig. 3.4 Musical Subdivison Example
(a) A measure containing four quarter notes subdivided into eighth notes and sixteenth notes. Notes labeled with a 1 are Downbeats. All numbers are Beats. + indicates an 8th Note Syncopation while *e* and *a* indicate 16th Note Syncopations.
(b) Labeled notes of the sixth measure of the excerpt. The measure contains 1 Downbeat, 3 Beats (excluding the Downbeat), 4 8th Note Syncopations and 3 16th Note Syncopations.

percussionist used to play each note. Percussionists were separated into right-handed and left-handed groups based on their handedness score. Similar to (Bacon 2014), the percentage of dominant and non-dominant strokes were computed for each of the four metrical groups, and 95% confidence intervals were calculated for both the right-handed and left-handed groups.

The performances of all percussionists were of very high quality with an average error of less than 2% in both sight-reading and the rehearsed performance. Mistakes were excluded from the calculations. For example, if the player made 1 mistake, percentages would be calculated out of 95 notes instead of 96.

3.2.5 Model Stickings

Model stickings were gathered from three professional, right-handed percussionists in the Montreal area. They serve as references for two distinct sticking strategies. Professional 1 and Professional 3 did not participate in the experiment other than providing their sticking. Both notated exactly the same sticking that follows right-hand lead. Their sticking will be referred to as Sticking 1 (Figure 3.5a).

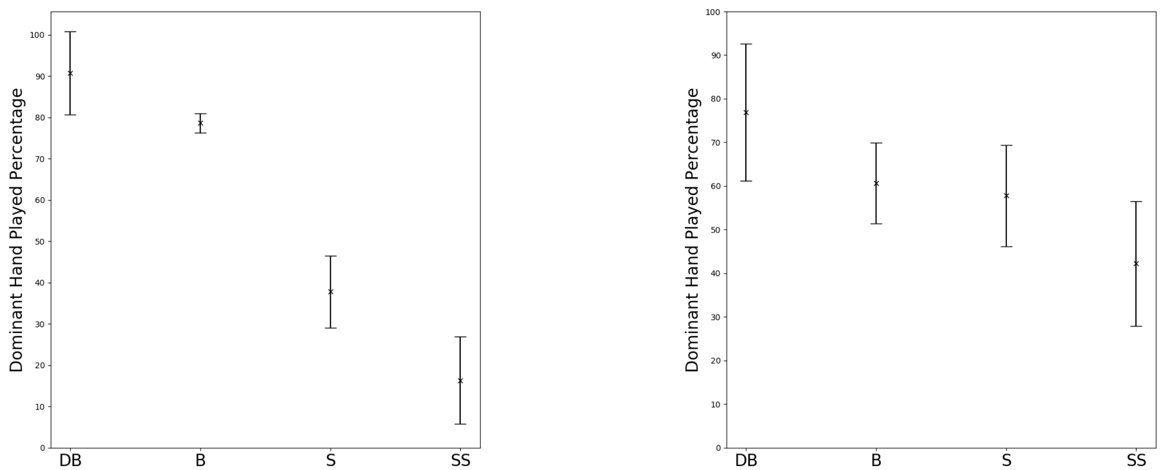
(a)

(b)

Fig. 3.5 Model Sticking Examples
Sticking 1 (a), right-hand lead, and Sticking 2 (b), alternating example. Note for Sticking 1 how all beats are played by the right hand, even if the preceding note was also played by the right hand. In Sticking 2, regardless of metrical importance of any single note, the alternating pattern is maintained throughout each measure.

Professional 2, also Right 1 in this study, reported a preference to alternate when the option is available. The alternating sticking notated by Professional 2 will be referred to as Sticking 2 (Figure 3.5b). In this sticking, measures were more often initiated using the dominant hand, leading to downbeats and beats being played with the dominant hand, though less often than in Sticking 1.

Interestingly, Professional 2 was the only right-handed percussionist in the experiment to report no preference of lead hand when playing percussion (Table 3.1). Their lack of preference aligns with their partiality to alternating sticking. However, the sticking that Professional 2 suggested is very different from the sticking they used in the experiment. In fact, the sticking used in the experiment very closely resembles a right-hand lead sticking.



(a) (b)

Fig. 3.6 Sight-reading Sticking Distributions
Sight-reading dominant hand distribution with 95% confidence intervals for right-handed (a) and left-handed (b) players.
DB = Downbeats, B = Beats, S = Syncopations, SS = Sixteenth Syncopations.

3.2.6 Effects of Pedagogy

Due to the teacher-student oral tradition of percussion, it is necessary to note the effect of the instructor's playing strategy upon the student's. If the teacher has had great success due to right-hand lead over their career, they will pass this bias to the student. Similarly, if the teacher believes strongly in perfect symmetry at all times, the student is likely to prefer alternate sticking. However, a student is likely to have several instructors through their career and how the unique pedagogical strategies between instructors affect the student's development has not been thoroughly investigated.

In general, the natural hand skill asymmetry evident in students is well known to percussion pedagogues. For this reason, it is especially important for beginning players to work on symmetry between hands (Delecluse 1969; McClaren 1994). Without this foundation, players will not have the flexibility in sticking choice to play more complicated music. However, once a decent level of symmetry has been established, percussionists are free to play as they choose. This is similar to the jazz concept of learning the rules, so you know when break them. By utilizing a right-hand lead strategy, percussionists are able to leverage their asymmetry to their advantage. This fact, combined with the pervasiveness of right-hand lead in pedagogy makes it a 'default' sticking for some players.

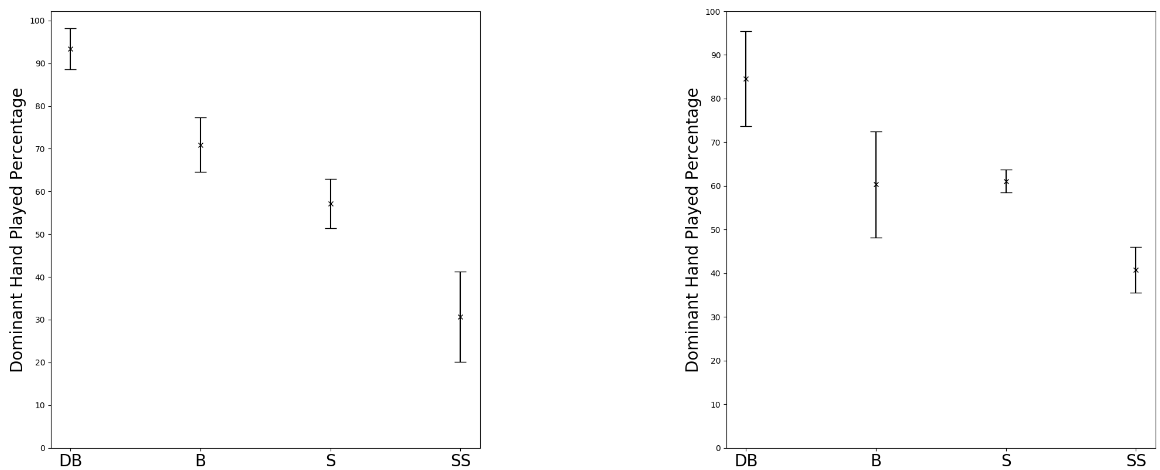
3.3 Results

We begin by exploring general trends in sticking strategies of the right-handed and left-handed groups for the sight-reading and rehearsed performance. Differences between the groups are discussed as well as how each group adjusts their strategies between trials. Given the large confidence intervals present in the left-handed group, distinct sub-groupings of playing strategy are further explored in Section 3.3.5.

3.3.1 Sight-reading

Percussionists strongly prefer to use their dominant hand for downbeats (the most metrically important note type). They tend to prefer their dominant hands for beats as well; however, the degree of preference depends on handedness. There is a clear preference in the right-handed group (Figure 3.6a) while only barely so for the left-handed group. The difference between right and left-handed players becomes more obvious by observing hand use for the smaller subdivisions of the beat, especially the sixteenth syncopations. Right-handed players are more likely to play with the non-dominant hand, while there is a much smaller difference for left-handed players (Figure 3.6b).

The data used in (Bacon 2014) was acquired from the authors and analyzed using the same procedure as the current study. Similar to the results in the current study, both groups strongly prefer their dominant hand for downbeats. Also, the correlation between dominant hand use and metrical importance is stronger in the right-handed group (Figure 3.7a) than the left-handed group (Figure 3.7b). The sharp decline in dominant hand use as metrical importance decreases suggests a preference for a right-hand lead sticking for the right-handed group. While the left-handed group



(a) (b)

Fig. 3.7 Bacon Sticking Distributions
Dominant hand distribution with 95% confidence intervals for right-handed (a) and left-handed (b) players from (Bacon 2014). DB = Downbeats, B = Beats, S = Syncopations, SS = Sixteenth Syncopations.

prefers to use their dominant hand for metrically important notes, they do not adhere as closely to a left-hand lead sticking. This also agrees with the findings of the current study.

As can be seen in Table 3.4, the confidence intervals for Bacon's left-handed group are much larger for downbeats and beats and much smaller for both syncopations and sixteenth syncopations. This is in contrast to the results of the current study. However, despite the fact that left-handed intervals are only larger for some note types in Bacon's data, the average across all types is higher for left-handed players than for right-handed players, 7.72% and 6.88%, respectively. While not as stark, greater variability for the left-handed group, indicated by the confidence intervals, agrees with the results of the current study. The distinct sticking strategies of the left-handed players in the current study cause the discrepancies in magnitude of difference in confidence intervals between the current work and that of (Bacon 2014).

Table 3.4 Confidence Interval Comparison
Confidence interval sizes for both Bacon's data and the current data divided by note class.

		Downbeats	Beats	Eighth	Sixteenth
Marci	Right	10.1%	3.7%	8.7%	10.6%
	Left	15.7%	10.9%	11.6%	14.3%
Bacon	Right	4.8 %	6.4%	5.8%	10.5%
	Left	10.9%	12.2%	2.6%	5.2%

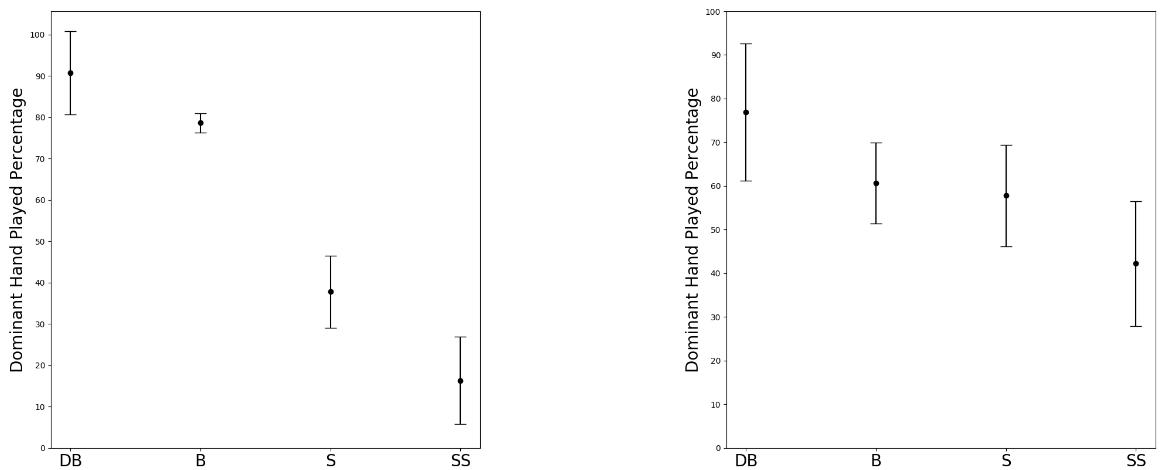
3.3.2 Rehearsed Performance

Both groups in the current study strongly prefer their dominant hand for downbeats in the rehearsed performance as well (Figure 3.8). Right-handed players also show clear preference for their dominant hand for beats and for their non-dominant hand for sixteenth syncopations. This is contrasted again by only slight preference in the left-handed group. Interestingly, the confidence intervals for the right-handed players are much smaller for the rehearsed performance than the sight-reading, indicating a trend toward a single, common sticking. This is not true for the left-handed players. This result is further discussed in the following section.

3.3.3 Model Sticking Comparison

Figure 3.9a compares the rehearsed performance sticking distributions for right-handed players with Sticking 1. Right-handed players align closely with the right-hand lead strategy of Sticking 1 (see also Table 3.5). All but the sixteenth syncopation values fall within the 95% confidence intervals. This shows good agreement with the right-hand lead strategy.

Left-handed players more closely match the alternating strategy of Sticking 2 (Figure 3.9b). They do not rely as much on their dominant hand for downbeats and beats compared to the right-handed players. They also are more even with respect to hand use for smaller subdivisions of the beat.



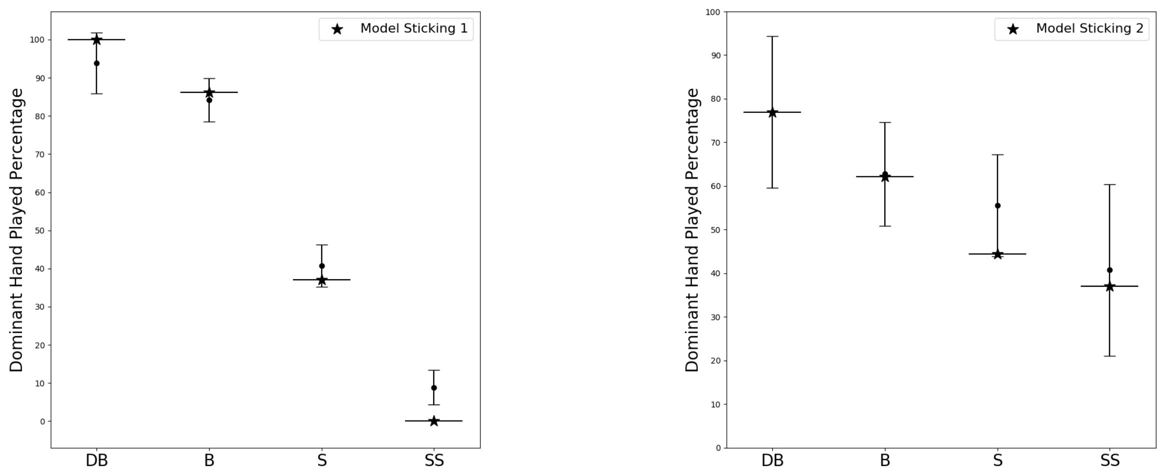
(a) (b)

Fig. 3.8 Rehearsed Performance Sticking Distributions
Rehearsed performance dominant hand distribution with 95% confidence intervals for right-handed (a) and left-handed (b) players. DB = Downbeats, B = Beats, S = Syncopations, SS = Sixteenth Syncopations.

3.3.4 Sight-reading vs. Rehearsed Performance

The most remarkable fact regarding the sight-reading and rehearsed performances is the differences between the right-handed and left-handed groups. The right-handed players, on average, made clear changes between the sight-reading and rehearsed performance. The left-handed group also made concerted changes between the two readings. However, these changes were not toward a singular goal, like in the right-handed group. There was little difference in terms of expertise between the two groups, $M_{\text{training}} = 13.8$, $SD = 4.2$, range$= 8 - 18$ and $M_{\text{training}} = 14.2$, $SD = 4.9$, range$= 7 - 18$, for the right-handed and left-handed groups, respectively.

As seen in Table 3.5, the right-handed group shows a clear trend toward a strict right-hand lead strategy (Sticking 1) between the sight-reading and rehearsed performance. The average sticking score increased by 5.6 from 82.7 to 88.3. The scores of the right-handed group are much greater than the left-handed group for either sticking except for Left 1. This will be further discussed in



(a) (b)

Fig. 3.9 Rehearsed Performance Sticking Distributions vs. Model Stickings
Rehearsed performance sticking distribution for right-handed players with Sticking 1 (a) and left-handed players with Sticking 2 (b). DB = Downbeats, B = Beats, S = Syncopations, SS = Sixteenth Syncopations.

the following section.

The prevalence of right-hand lead in percussion pedagogy combined with the right-handed player's strong preference for their right hand, indicated by their handedness scores, suggest pressure to play a certain way. When not having to worry about processing new information, like during sight-reading, their training takes over, pushing right-handed players to more closely follow a right-hand lead sticking during the rehearsed performance.

3.3.5 Left-handed Sticking Strategies

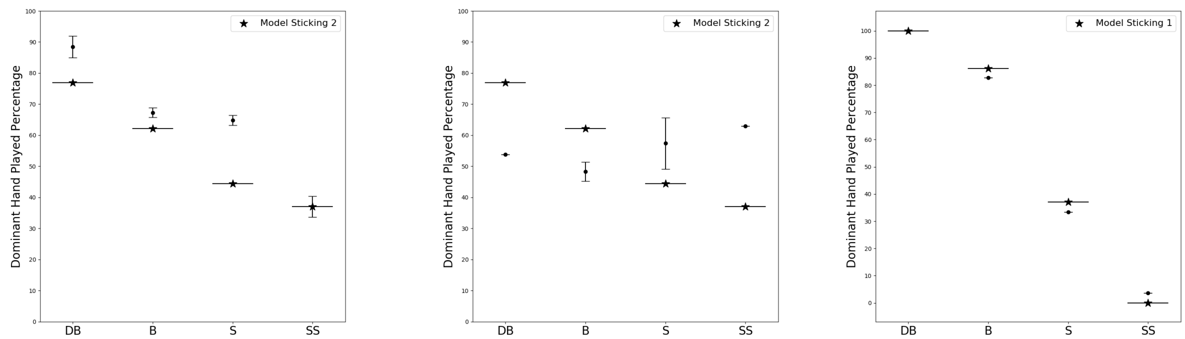
The large confidence intervals in the left-handed group (Figure 3.6b and 3.7b) are not caused by individual discrepancies or mistakes in sticking but by consistent, differing strategies (Table 3.5). The intervals did not grow smaller for the rehearsed performance because the three strategies remained distinct, unlike the right-handed group where all the players trended toward a similar sticking.

Table 3.5 Individual Model Sticking Scores
Model stickings scores for sight- reading and the rehearsed performance. Scores were calculated by comparing the hand choice of the model sticking to that of each participant for each note. The sticking with the higher score is shown except for Left 4 and Left 5. Their strategy is a combination of Sticking 1 and Sticking 2, thus scoring similarly for both model stickings.

	Sticking 1	Sticking 2
Left 1	83.5⇒93.2	
Left 2		40.8⇒63.1
Left 3		66.1⇒63.1
Left 4	59.2⇒67.9	59.2⇒68.9
Left 5	60.2⇒65.1	59.2⇒68.9
Right 1	75.7⇒81.5	
Right 2	89.3⇒91.3	
Right 3	89.3⇒92.2	
Right 4	90.3⇒93.2	
Right 5	68.9⇒83.4	

The first group, consisting of Left 4 and Left 5, use a hybrid of a traditional, left-hand lead sticking and the alternating sticking (Figure 3.10a). These players prefer to use their dominant hand for downbeats and beats though not as much as in Sticking 1, while aligning more closely with Sticking 2 for syncopations, especially sixteenth syncopations. This combination of stickings is why this group improved their scores for both Sticking 1 and Sticking 2 between the sight-reading and rehearsed performance, as shown in Table 3.5. These are also the players who reported leading with their left hand (Table 3.1). It appears that players who report using their dominant hand more closely follow right/left-hand lead than do those that reported no preference, regardless of handedness.

The second group, Left 2 and Left 3, prefers to alternate regardless of metrical importance of the note. Hand choice for all note types is split approximately 50/50 between dominant and non-dominant (Figure 3.10b). These are also the two players who reported no preference for lead hand. Since they always alternate, there is no need to prefer one hand over the other. Left 3 did not change their sticking much between the two readings. However, Left 2 made adjustments that placed their dominant hand at the beginning of phrases, leading to a much higher score for the rehearsed performance than for the sight-reading (Table 3.5).

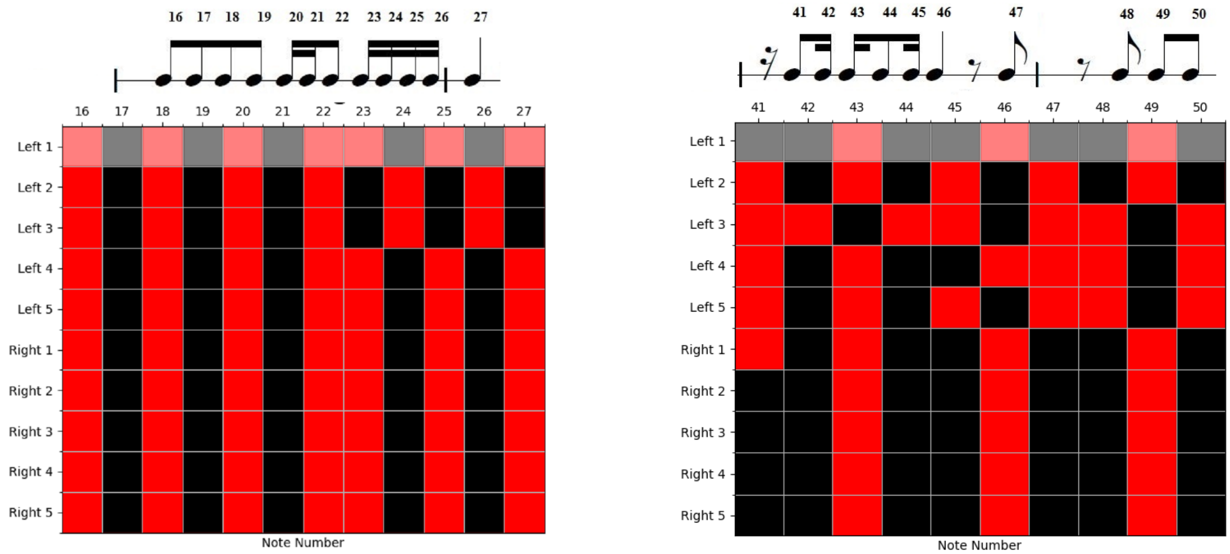


(a) (b) (c)

Fig. 3.10 Left-handed Sticking Groups
Rehearsed performance sticking distribution of left-handed groups compared to model stickings. (a) Left 4 and Left 5 versus Sticking 2, alternating. (b) Left 2 and Left 3 versus Sticking 2. (c) Left 1 versus Sticking 1, right-hand lead.

Similar to the second group, Left 1, the sole member of the final group, reported no preference for lead hand (Table 3.1). However, the result of this lack of preference is entirely different than the second group. Left 1 is anomalous in their use of the right hand as the lead hand when playing. Instead of left-hand lead, Left 1 plays like a right-handed player using right-hand lead. The apparent lack of preference when asked sharply contrasts with the performance data. It is possible that Left 1 uses their left hand for other musical purposes that were not tested that validates their report of no preference. However, the present results indicate a strong right-handed preference in Left 1.

When asked, Left 1 attributed their strategy to a strict, right-handed teacher. Left 1's hand choices have been reversed to reflect that despite preferring their left hand in daily life, the right hand is the dominant hand when performing percussion. It is clear in Figure 3.10c that Left 1 closely follows the right-hand lead sticking strategy due to the strict training they received. This can also be seen in their high scores for Sticking 1 in Table 3.5.



(a) (b)

Fig. 3.11 Beat Matrics: Notes 16-27, Notes 41-50
Normalized beat matrics showing hand use of all percussionists.
red = dominant hand, black = non-dominant hand
(a) Notes 16 - 27. Left 2 and Left 3 alternate, while all other players double stroke at Notes 22 and 23 with their dominant hands to maintain their right/left-hand lead strategy.
(b) Notes 41 - 50. Left 1 and Right 2 - 5 closely follow a right-hand lead sticking, using their non-dominant hand for syncopations and playing only notes that fall on the beat with their dominant hand. Left 2 - 5 utilize different combinations of strategies.

3.3.6 Musical Context of Sticking Strategies

Certain rhythms within the excerpt are especially good for showcasing the different sticking strategies. These rhythms are challenging enough that they cannot be played with a single hand but not so complex that there is only one possible way to perform them. Figure 3.11 shows the normalized hand choice in the rehearsed performance for individual notes in two sections of the excerpt. By indicating notes played by the right hand for right-handed players and left hand for left-handed players using the same color, common patterns emerge. Left 1's row is lightened to indicate that their hand choice has been reversed to ease recognition.

The Measures 6 - 7 (Figure 3.11a) offer an example of the difference between players who prefer right/left-hand lead compared to those who prefer to alternate. Those that prefer right/left-hand lead will use their dominant hand (red squares in the beat matrix) for all notes that fall on the beat (Notes 16, 20, 23, and 27). All players begin the measure with their dominant hand, and due to the even number of notes in the first two beats (Notes 16 - 20), this can achieved by simply alternating hands for each note. However, since beat 3 has an odd number of notes (Notes 20 - 22), percussionist must use their dominant hand for two notes in a row (Notes 22 and 23), known as a double stroke, to maintain the pattern of dominant hand use on beats. This strategy is used by all percussionists except for Left 2 and Left 3, since both these players prefer to alternate.

Measures 9 - 10 (Figure 3.11b) also show patterns in hand use; however, they are not as clear since the rhythm is more complex with its many syncopations. Of the first 5 notes, only one is on the beat (Note 43). The other 4 are 16th note syncopations, the smallest subdivision in the excerpt. Given this information, we would expect players who utilize right/left-hand lead to play Note 43 with their dominant hand and Notes 41, 42, 44, and 45 with their non-dominant hand. This is the case for Left 1 and Right 2 - 5. Interestingly, Left 3 shows the exact opposite pattern. This indicates a right-hand lead sticking despite being left-handed, similar to Left 1. The other players use combinations of right/left-hand lead and alternating sticking.

Left 2 stays consistent in their strategy and alternates for the entire section, regardless of metrical value of each note. Though Right 1 generally follows right-hand lead, they confirm their reported preference to alternate with small deviations from the prescribed sticking, like Note 41. Right 1 starts the measure with the dominant hand despite the first note falling on a syncopation. They reported preferring to alternate when possible and set themselves up to do so by playing the first note of the pattern with the dominant hand; however, they adjust their strategy shortly thereafter at Note 45 to follow right-hand lead.

The most interesting stickings are those of Left 3 - 5. Both Left 4 and Left 5 begin the measure by alternating but have both deviated by Note 47. From Note 47 - 50, once again, we see left-handed players using a right-hand lead strategy instead of their reported preference for left-hand lead. This phenomena is even more apparent in Left 3 who uses right-hand lead for the entire section.

3.4 Conclusion

The tenets of percussion pedagogy are, at their core, realist. While perfect symmetry between hands is the goal, there is an explicit understanding that a player's dominant hand will be favored due to its reliability in both quality of sound and rhythmic accuracy (McClaren 1994; Peters 1986). This preference is reflected in sticking strategies recommended by traditional percussion pedagogy: notes of greater rhythmical importance are more likely to be played by the dominant hand (McClaren 1994). The effect of these tenets are clearly illustrated in our results. The reliance on the dominant hand for metrically important notes shown in the present study also agrees with the results of Bacon (2014). Furthermore, due to the larger number of left-handed players in this study, we were able to determine that the degree of reliance on the dominant hand is related to handedness. The uniformity present in the right-handed players' stickings is likely explained by their strong preference for their right hand in every day life in conjuntion with the bias toward the right hand present in percussion pedagogy. The most common sticking is not 'dominant-hand lead' but 'right-hand lead'. However, handedness can be overwritten by training, as shown by Left 1's right-hand lead strategy despite their natural left-handedness.

In addition, since the handedness scores of the right-handed players are more extreme than the left-handed players' scores, perhaps relying on their dominant hand is more effective for the right-handed group than the left-handed group. Because left-handed players do not have as strong a preference for their dominant hand, they do not benefit as much from playing left-hand lead and are more likely to alternate. This is further supported by the fact that the Sticking 2, provided by the only right-handed player that reported no preference for lead hand, alternates more often than Sticking 1, the preferred sticking for right-handed players.

We also found that there are differences between the sticking strategies used for sight-reading and those used for the rehearsed performance. All players except Left 3 more closely followed a model sticking for the rehearsed performance than the sight-reading (Table3.5). When allowed to rely on their instrumental training, percussionists perform in a more uniform manner.

Chapter 4

Effects of Handedness on Performance Kinematics

4.1 Introduction

Several researchers have investigated the kinematics of percussion performance and identified how players adjust muscle use for greater movement efficiency (Fujii et al. 2009; Fujisawa and Miura 2010), how the gestures differ when striking different playing surfaces (Dahl 2004), differences when performing various articulations (Bouënard, Wanderley, and Gibet 2010; Chen et al. 2016), as well as asymmetries between the movements of each hand (Bacon 2014; Dahl 2011). However, only minimal work has been done to directly measure the effects of handedness on percussion performance.

In the previous chapter, we demonstrated the differences in playing strategy caused by handedness. However, it is still unclear if these differences in playing strategy are related to differences in mallet trajectory. Past research has demonstrated unique patterns in the trajectory of a single mallet related to articulation (Bouënard, Wanderley, and Gibet 2010; Chen et al. 2016). However, it remains unclear if similar systematic differences are present between the trajectories of both hands.

In this chapter, we focus on the second set of hypotheses, those that deal with stroke kinematics. To investigate these types of questions, we had participants perform the experiment explained in the following section.

4.2 Methodology

4.2.1 Design and Procedure

The neutral task is named as such due to its lack of complex musical elements. Without changing rhythm, loudness, or articulation, the task requires percussionists perform only those actions that are needed to produce sound with good tone quality. In this way, this musically neutral task is similar to musical warm ups. During warm ups, players perform the actions required to make music by playing simplified rhythms in order to focus on their fundamentals. By designing the experiment in this way, we were able to directly observe the mechanics of timpani playing without any artifacts that may be introduced into the data when percussionists need consider musical requirements like changing rhythm or dynamics.

The same 10 percussionists analyzed in the previous chapter also performed the neutral task, which was comprised of five trials. During each trial, the performer played 32 alternating strokes of one articulation on a single timpani at a comfortable dynamic. The five articulations (accent, legato, staccato, tenuto, and vertical accent) were chosen to match earlier work (Bouënard, Wanderley, and Gibet 2010; Chen et al. 2016) and to showcase the gestures needed to perform a wide array of timbres. Players were given no instruction as to which hand would start.

By comparing the mallet trajectories of all participants, we sought to confirm patterns related to each articulation that could be generalized across participants. Furthermore, data from each percussionist's left and right mallets were compared to identify systematic differences caused by handedness.

Before each trial, performers were asked to play with one of the five articulations. Similar to the experiment discussed in the previous chapter, a metronome played four beats at 90 beats per minute immediately preceding each trial. The metronome helped all trials for all players be performed at a consistent rate, so any trajectory variations between trials were due to differences in musical intention and not an artifact of the tempo.

4.2.2 Apparatus

To measure the movement of the player's body and mallets during the experiment, motion capture markers were arranged on the body of each participant. An array of 6 Qualisys Oqus 300 and 4 Oqus 700 cameras capturing at 350 frames per second were used to track the markers in addition to the video camera and microphone discussed in the previous chapter. 2 markers were placed in a mirrored pattern on each mallet in order to accurately measure the movement during each strike. Because the mallets can move at nearly 10 meters a second (Bouënard, Wanderley, and Gibet 2010; Dahl 2011), a high sampling rate is necessary for accurate and precise tracking.

Prior research has identified the mallet tip as the point that contains the most important kinematic information about the strike (Bouënard, Wanderley, and Gibet 2010; Dahl 2011; Dahl and Altenmüller 2008). For this reason, while 33 motion capture markers were placed on the participant's body and mallets, the analysis focuses on two markers specifically: the left and right mallet tips. By following these markers, we were able to identify differences in gesture caused by articulations as well as handedness.

4.2.3 Analysis

The height or z position was extracted for both the left and right mallets for all five articulations. The data streams were segmented into 500 point pieces centered about each stroke impact. This yielded 16 segments per hand. The first and last stroke of each hand were removed as outliers because of the small adjustments made by players directly before and after the trial (generally, larger playing gestures were used for the first and final notes). These 14 strokes per hand per trial gave us a total of 140 strokes for each percussionist. The velocity for each stroke was calculated by differentiating the position data (Equation 4.1). Finally, average velocity for each articulation was calculated by averaging the 14 strokes at each time step.

$$\text{velocity}^i \, \mathrm{m\,s^{-1}} = \frac{\text{position}^i - \text{position}^{i-1} \text{ m}}{\text{sample period s}} \tag{4.1}$$

$$i = \text{current sample}, \quad i-1 = \text{previous sample}, \quad \text{sample period} = \frac{1}{350}\,\mathrm{s}$$

The average trajectory for both hands for each articulation was calculated using the mean value at each of the 500 samples. Plots of the average trajectory as well as the raw data give insight into the systematic differences between each articulation as well as contrasting strategies utilized by the players. The average trajectory for both hands of each percussionist along with standard deviations are shown in Figure 4.1 - 4.10.

4.3 Articulation-related Differences

Previous research has emphasized the importance of visual cues in percussion performance. Percussion instruments, in general, have limited sustain. When the information in one mode (in this case, instrument sustain) is ambiguous, cross-modal information (visual gesture cues) can alter listener perception (Schutz and Lipscomb 2007; Wada, Kitagawa, and Noguchi 2003). Percussionists take advantage of this phenomena by using different gestures to help indicate the length of a note (Schutz and Lipscomb 2007; Voigt 2016). Small, fast motions communicate short notes while large, slower gestures indicate a more sustained sound (McClaren 1994).

Percussion pedagogy states that these different gestures change the resulting sound to an audible degree (McClaren 1994; McCormick 1983). Contrastingly, some research indicates that there may be no quantifiable acoustical qualities created by different stroke types (Saoud 2003). At the very least, visual information from the playing gesture has a major effect on the perceived length of percussion notes (Schutz and Lipscomb 2007). However, both Saoud (2003) as well as Schutz and Lipscomb (2007) focused on marimba, so these results may not be applicable in this context. Further research is required to measure the perceptual effects of gestural cues with timpani.

When focusing on the playing gesture alone, two aspects are often used to describe them: preparatory height and striking velocity (Bouënard, Wanderley, and Gibet 2010; Dahl 2004). By recording these quantities for each percussionist and articulation, systematic differences begin to appear between articulations.

4.3.1 Preparatory Height

Preparatory height refers to the distance between the mallet and drum head before the beginning of the striking motion. In this section, only the height of the dominant hand will be used. However, Section 4.4 covers the differences in preparatory height between hands.

In general, a higher stroke is used to play louder, while quieter notes are played from a lower height (McClaren 1994). Because the *accent* and *vertical* strokes are intended to be played louder than other articulations, it is not surprising that these two have the greatest preparatory height for the majority of players (Table 4.1). Since the other three articulations do not imply any extra force required to play, they could, theoretically, be performed from approximately the same height. While *legato* and *tenuto* are played from similar heights by most percussionists, *staccato* is not. These results are in contrast with some previous research (Bouënard, Gibet, and Wanderley 2008), in which there was little discrepancy between preparatory height for non-accented articulations (*legato*, *staccato*, and *tenuto*). However, the current study has a larger sample with a higher average participant skill level than the mentioned article. The wide range of height values between percussionists indicates that stroke height is greatly dependent on personal preference. Therefore, the differences in results between this and other studies could be related to selection bias given the relatively small sample sizes.

When Left 1 performs a *staccato* stroke, the mallet begins the downward motion from about 23 cm above the drum head (Table 4.1). This is only half the height of the preparation for the *legato* stroke. A similar trend can be seen in the other percussionists, where the *staccato* stroke begins from a much lower height than the other articulation types. In eight out of ten percussionists, *staccato* had the lowest preparatory height, and in all cases, the *vertical* articulation had the

Table 4.1 Preparatory Height (cm) by Articulation for Dominant Hand
Fr = French Grip Am = American Grip Gr = German Grip
italics = smallest value per percussionist
underline = largest value per percussionist

Percussionist	Grip	Accent	Legato	Staccato	Tenuto	Vertical
Left 1	Fr	54.6	52.7	***23.0***	50.6	**59.1**
Left 2	Am/Gr	69.1	54.5	***18.2***	59.5	**70.4**
Left 3	Fr	**40.4**	37.4	***32.4***	34.6	34.8
Left 4	Fr	30.4	26.1	25.0	***21.7***	**33.8**
Left 5	Gr	54.1	53.1	***28.3***	57.7	**73.9**
Right 1	Fr	***50.6***	52.8	58.1	60.5	**61.3**
Right 2	Am/Fr	35.8	41.1	***21.5***	35.3	**43.0**
Right 3	Fr	49.2	**55.1**	***28.7***	53.9	53.2
Right 4	Fr	37.8	36.3	***20.9***	32.6	**39.9**
Right 5	Am/Gr	16.8	20.1	***14.9***	17.3	**21.8**

highest preparation.

It is clear from Table 4.1 that different percussionists have vastly different average stroke heights. Ranging from around 20 cm for Right 5 to over 50 cm for Left 2 and Left 5. Interestingly, this is not in agreement with the expectation given the grip used by the players. French grip allows for greater range of movement, so it would be expected that percussionists using that grip would have greater preparatory height than those that used German grip (Bacon 2014; Bouënard, Wanderley, and Gibet 2010). While the lowest preparatory heights are displayed by Right 5, who uses a grip similar to German, the highest preparatory heights are shown by Left 2, who uses a nearly identical grip to Right 5. In addition, the only percussion who uses exclusively German grip, Left 5, falls in the middle. Given the small sample size, it is possible that a more expected trend would emerge if more percussionists were tested. However, regardless of choice of grip, by normalizing the raw preparatory heights, we may uncover trends in relative height between different articulation types. All heights were normalized using the height of the *legato* stroke, as that is the basic timpani stroke. The results can be seen in Table 4.2

The normalized heights show much better agreement between percussionists. *Accent* strokes are slightly larger than *legato* strokes for all left-handed percussionists, while they are slightly

Table 4.2 Normalized Preparatory Height by Articulation for Dominant Hand
italics = smallest value per percussionist
underline = largest value per percussionist

Percussionist	Accent	Legato	Staccato	Tenuto	Vertical
Left 1	1.03	1	0.43	0.96	1.12
Left 2	1.26	1	0.33	1.09	1.29
Left 3	1.08	1	0.86	0.92	0.93
Left 4	1.16	1	0.95	0.83	1.29
Left 5	1.01	1	0.53	1.08	1.39
Right 1	0.95	1	1.09	1.14	1.16
Right 2	0.87	1	0.52	0.85	1.04
Right 3	0.89	1	0.52	0.97	0.96
Right 4	1.07	1	0.58	0.92	1.06
Right 5	0.81	1	0.69	0.89	1.04

smaller for most right-handed percussionists. However, it is unclear if this is related to handedness or merely caused by the particular players that participated. *Staccato* strokes, with an average height only 0.65 times that of the *legato* stroke, tend to be significantly smaller regardless of handedness. *Tenuto* strokes are about 96% of the *legato* height. *Vertical* strokes are still the largest with an average height about 1.13 times as high as the *legato* average. The increased agreement between relative heights of strokes appears to indicate that while percussionists may play at a height that is comfortable to them, they share a common strategy regarding the relative heights required to play each articulation.

4.3.2 Velocity Maxima

However, height does not tell the whole story. Because the mallets must travel a greater distance in the same amount of time, larger motions tend to require faster movement than smaller gestures (Dahl 2011; Dahl and Altenmüller 2008; Dahl, Großbach, and Altenmüller 2011). This would suggest that *staccato* strokes would have significantly lower velocity than the other stroke types, while *vertical* strokes should have the greatest striking velocity. As can be seen in Table 4.3, this is true for the *vertical* strokes, but *staccato* strokes are slowest for only three players. In fact, the *legato* articulation possesses the lowest downward velocity in six out of ten participants.

Furthermore, for two of the three with a slower *staccato*, the difference between *legato*, and *staccato* is less than 0.1 meters per second. The slower, longer motion used for *legato* signals to the audience that the note is long, while by traveling a short distance at a velocity that is higher than expected, percussionists are able to more effectively communicate the short, pointed nature of the *staccato* articulation.

Table 4.3 Maximum Striking Velocity (m/s) by Articulation
italics = smallest value per percussionist
underline = largest value per percussionist

	Accent	**Legato**	**Staccato**	**Tenuto**	**Vertical**
Left 1	-5.58	***-4.13***	-4.18	-5.69	**-8.20**
Left 2	-7.74	***-5.32***	-6.39	-6.92	**-8.58**
Left 3	-3.38	-2.65	***-2.61***	-2.51	**-5.15**
Left 4	-5.86	***-3.71***	-4.80	-4.21	**-5.69**
Left 5	-5.31	***-4.21***	-5.05	-5.52	**-7.88**
Right 1	-6.44	-4.51	***-4.50***	-5.18	**-7.19**
Right 2	-3.65	-2.52	***-2.04***	-2.19	**-4.17**
Right 3	-6.37	-4.64	-4.64	***-4.42***	**-7.59**
Right 4	-6.95	***-3.97***	-5.75	-5.55	**-7.95**
Right 5	**-5.40**	***-2.95***	-5.04	-4.04	-4.23

Table 4.4 Normalized Maximum Striking Velocity by Articulation
italics = smallest value per percussionist
underline = largest value per percussionist

	Accent	**Legato**	**Staccato**	**Tenuto**	**Vertical**
Left 1	1.35	1	1.01	1.37	1.98
Left 2	1.45	1	1.20	1.29	1.61
Left 3	1.27	1	0.98	0.94	1.94
Left 4	1.58	1	1.29	1.13	1.53
Left 5	1.26	1	1.20	1.31	1.87
Right 1	1.42	1	0.99	1.15	1.59
Right 2	1.44	1	0.80	0.87	1.65
Right 3	1.37	1	1.00	0.95	1.63
Right 4	1.74	1	1.44	1.39	1.99
Right 5	1.83	1	1.71	1.37	1.43

Similar to the preparatory height, the raw striking velocity values vary greatly between percussionists. However, if normalized relative to the *legato* velocity, they become more uniform.

Despite *staccato* strokes having a much lower preparatory height, the velocity is often as fast or slightly faster than the *legato*. On the opposite end of the spectrum, the *vertical* stroke has an average preparatory height that is 1.13 times that of the *legato* stroke while having a striking velocity that is 1.72 times higher. A more symmetrical trend can be seen in the *tenuto* strokes. With a preparatory height that is 1.13 times that of *legato*, *tenuto* strokes have a striking velocity an average of 1.18 times as high.

4.4 Handedness-related Differences

In the previous section, we highlighted two measures that were of interest when comparing the different stroke articulations. Now, these same values will be compared between hands in order to investigate the effects of handedness.

Table 4.5 shows the raw preparatory height for each hand as well as the standard deviations to illustrate the similarity between hands. In almost all cases, the standard deviations cause the left and right values to overlap, indicating that there is not a large difference between preparatory height for each hand. The left hand is higher for most articulations in the left-handed players, but the degree of difference is not consistent. Interestingly, the left hand is higher for many articulations for the right-handed players as well, with the difference between hands being smaller for right-handed players than for the left-handed group.

Similar to preparatory height, the maximum striking velocities do not differ significantly between the hands, as can be seen in Table 4.6. However, the right hand tends to have greater values than the left, which is exactly opposite the trend in preparatory height. This is especially true for the left-handed players.

Given the small differences between the two hands with respect to preparatory height and striking velocity for a given articulation, it is clear that percussionists use similar strategies between hands when playing a single articulation. The more uniform relative heights and velocities point to a shared idea of each articulation. While percussionists perform differently, there is an internal consistancy. This is particular relevant to percussion pedagogy where students may not perform in

Table 4.5 Preparatory Height (cm) by Articulation for Both Hands

	Accent		Legato		Staccato	
	Left	**Right**	**Left**	**Right**	**Left**	**Right**
Left 1	54.6 ± 1.63	48.6 ± 2.36	52.7 ± 3.09	47.7 ± 2.19	23.0 ± 3.07	25.0 ± 3.13
Left 2	69.1 ± 2.38	69.9 ± 1.11	54.5 ± 0.81	55.7 ± 1.59	18.2 ± 3.75	15.5 ± 1.85
Left 3	40.4 ± 2.48	39.2 ± 2.37	37.4 ± 1.46	35.5 ± 0.94	32.4 ± 1.02	31.5 ± 0.79
Left 4	30.4 ± 2.62	29.7 ± 1.94	26.1 ± 1.97	24.5 ± 3.37	25.0 ± 2.80	20.1 ± 4.35
Left 5	54.1 ± 2.80	50.4 ± 2.13	53.1 ± 3.31	47.2 ± 1.28	28.3 ± 2.41	31.2 ± 0.68
Right 1	50.6 ± 1.80	51.2 ± 1.25	52.8 ± 1.57	55.1 ± 1.68	58.1 ± 1.46	57.9 ± 1.33
Right 2	35.8 ± 0.90	34.6 ± 1.22	41.1 ± 2.53	39.9 ± 2.95	21.5 ± 3.04	19.2 ± 1.84
Right 3	49.2 ± 1.54	48.1 ± 1.64	55.1 ± 1.98	54.7 ± 1.50	28.7 ± 2.48	28.9 ± 1.71
Right 4	39.0 ± 1.51	37.8 ± 1.64	36.4 ± 1.43	36.2 ± 1.30	21.2 ± 0.76	20.9 ± 0.93
Right 5	17.4 ± 2.17	16.8 ± 2.34	21.4 ± 1.27	20.1 ± 1.50	14.9 ± 3.10	14.9 ± 2.55

	Tenuto		Vertical	
	Left	**Right**	**Left**	**Right**
Left 1	50.6 ± 3.05	47.1 ± 2.34	59.1 ± 2.28	58.2 ± 1.79
Left 2	59.5 ± 1.89	62.7 ± 1.42	70.4 ± 1.58	70.8 ± 1.02
Left 3	34.6 ± 1.91	34.6 ± 1.02	34.8 ± 1.67	35.5 ± 0.65
Left 4	21.7 ± 2.04	17.4 ± 3.44	33.8 ± 2.01	30.1 ± 2.47
Left 5	57.7 ± 5.61	47.4 ± 4.05	73.9 ± 4.27	73.8 ± 2.20
Right 1	60.5 ± 3.31	58.1 ± 4.01	61.3 ± 3.16	60.1 ± 3.50
Right 2	35.3 ± 1.94	33.8 ± 1.64	43.0 ± 2.19	42.4 ± 3.24
Right 3	53.9 ± 2.28	56.7 ± 2.37	53.2 ± 1.85	51.4 ± 1.71
Right 4	33.7 ± 0.90	32.6 ± 0.88	38.8 ± 1.20	39.9 ± 0.67
Right 5	19.2 ± 2.23	17.3 ± 2.33	22.4 ± 2.45	21.8 ± 1.60

exactly the same way as their teachers, but information about how gestures are performed relative to one another is successfully communicated.

4.4.1 Stroke Trajectory

While the prepartory height and striking velocity provided interesting points of comparison between the hands, the complete trajectory gives a clearer picture of the differences. Figures 4.1-4.10 show the average stroke trajectory for both the right and left hand for each percussionist separated by articulation. The standard deviation is included every 25 samples to illustrate the change over time.

Table 4.6 Maximum Striking Velocity (m/s) by Articulation for Both Hands

	Accent		**Legato**		**Staccato**	
	Left	**Right**	**Left**	**Right**	**Left**	**Right**
Left 1	-5.58 ± 0.34	-5.83 ± 0.35	-4.13 ± 0.18	-4.43 ± 0.28	-4.18 ± 0.14	-4.41 ± 0.19
Left 2	-7.74 ± 0.31	-7.63 ± 0.21	-5.32 ± 0.26	-5.02 ± 0.27	-6.40 ± 0.21	-5.97 ± 0.23
Left 3	-3.38 ± 0.27	-3.67 ± 0.24	-2.65 ± 0.24	-2.56 ± 0.26	-2.62 ± 0.14	-2.85 ± 0.19
Left 4	-5.86 ± 0.24	-6.10 ± 0.25	-3.71 ± 0.19	-3.86 ± 0.14	-4.80 ± 0.22	-5.29 ± 0.27
Left 5	-5.31 ± 0.30	-5.84 ± 0.27	-4.21 ± 0.21	-4.46 ± 0.39	-5.05 ± 0.32	-5.43 ± 0.56
Right 1	-6.27 ± 0.32	-6.44 ± 0.27	-4.27 ± 0.20	-4.51 ± 0.15	-4.74 ± 0.30	-4.50 ± 0.30
Right 2	-3.38 ± 0.27	-3.67 ± 0.24	-2.33 ± 0.12	-2.52 ± 0.22	-2.30 ± 0.23	-2.04 ± 0.32
Right 3	-6.54 ± 0.28	-6.37 ± 0.14	-4.48 ± 0.17	-4.65 ± 0.12	-4.63 ± 0.25	-4.65 ± 0.31
Right 4	-7.06 ± 0.42	-6.96 ± 0.35	-3.91 ± 0.28	-3.98 ± 0.23	-5.92 ± 0.53	-5.75 ± 0.32
Right 5	-5.24 ± 0.33	-5.40 ± 0.37	-2.80 ± 0.15	-2.95 ± 0.13	-4.74 ± 0.32	-5.05 ± 0.17

	Tenuto		**Vertical**	
	Left	**Right**	**Left**	**Right**
Left 1	-5.70 ± 0.26	-5.83 ± 0.26	-8.20 ± 0.35	-8.39 ± 0.25
Left 2	-6.92 ± 0.24	-6.94 ± 0.39	-8.59 ± 0.28	-8.50 ± 0.25
Left 3	-2.51 ± 0.15	-2.52 ± 0.18	-5.16 ± 0.33	-5.58 ± 0.31
Left 4	-4.22 ± 0.27	-4.33 ± 0.33	-5.69 ± 0.24	-6.18 ± 0.27
Left 5	-5.52 ± 0.38	-6.04 ± 0.2	-7.88 ± 0.36	-8.66 ± 0.33
Right 1	-4.73 ± 0.20	-5.18 ± 0.38	-6.44 ± 0.29	-7.20 ± 0.59
Right 2	-2.04 ± 0.13	-2.20 ± 0.22	-3.85 ± 0.27	-4.18 ± 0.24
Right 3	-4.25 ± 0.17	-4.43 ± 0.21	-7.56 ± 0.28	-7.59 ± 0.21
Right 4	-5.26 ± 0.34	-5.55 ± 0.26	-7.80 ± 0.55	-7.95 ± 0.32
Right 5	-3.71 ± 0.22	-4.04 ± 0.15	-3.88 ± 0.14	-4.23 ± 0.13

There are only a few points where the right and left mallet trajectory's variations do not overlap. These are confined primarily to Left 5. This player's style is much more variable than the other percussionists, and this fact can be observed by comparing Figure 4.5 to the others. Interestingly, this is not related to relative skill level, in this case. Left 5 has one of the highest number of years of training among participants. Instead, we hypothesize the variability is related to this players unique playing style.

The standard deviations are especially large for Left 5 compared to the other players when considering the trajectory before and after the impact. However, in all cases, the trajectory immediately preceding and immediately following the impact have very low variability with much overlap between hands. This indicates that while the preparatory motion may differ from stroke to stroke and between hands, the actual strike is extremely consistent. This consistency in the striking motion speaks to Left 5's experience; the variability in the movements between strokes allow them to express their 'free' playstyle.

4.5 Conclusion

The results discussed in this chapter confirm the findings of some past research as well as provide novel information regarding the effects of handedness on performance kinematics. To be able to compare to past work, preparatory height and striking velocity were chosen as the most salient factors. Once extracted, these measures showed clear trends for different articulations but varied widely between percussionists. In general, *vertical* strokes had both the highest preparatory height as well as striking velocity. This agrees with earlier work; the more distance traveled by the mallet, the faster it must travel (Bouënard, Gibet, and Wanderley 2008; Bouënard, Wanderley, and Gibet 2010; Dahl 2011; Dahl and Altenmüller 2008). Contrastingly, the results regarding *staccato* strokes do not follow this trend. *Staccato* strokes had the lowest preparatory height for most percussionists, but the striking velocity was often the middle value for the five articulations. With a short, fast motion, percussionists were able to better communicate that the listener should perceive the note as short. The degree to which this adjustment of gesture changes the sound quality of timpani is a topic of future work. However, results on marimba indicate that there may be little difference between the sounds created using different stroke types (Saoud 2003). At the very least, visual cues strongly effect the perception of note length in percussion (Schutz and Lipscomb 2007; Voigt 2016).

Though general trends were identified between percussionists, physiological differences between percussionists (height, arm length) caused raw values to vary greatly. However, by normalizing the values for each percussionist by the legato stroke values, clearer patterns emerged. There was good agreement between four out of five right-handed players for the relative heights of *staccato* and *vertical* (Table 4.2), about 60% and 102% of the *legato* height, respectively. In contrast, there was a wider spread of values for the left-handed group. Unfortunately, it is unclear if this is due to handedness or only an artifact of the small sample size. Regardless, it is worth noting that patterns in relative stroke height follow a similar trend to sticking strategy discussed in the previous chapter; the right-handed players in the study tend to be more similar than the left-handed players. Further research is required to confidently identify handedness as the true cause of these differences, but these results provide an interesting early exploration of the topic.

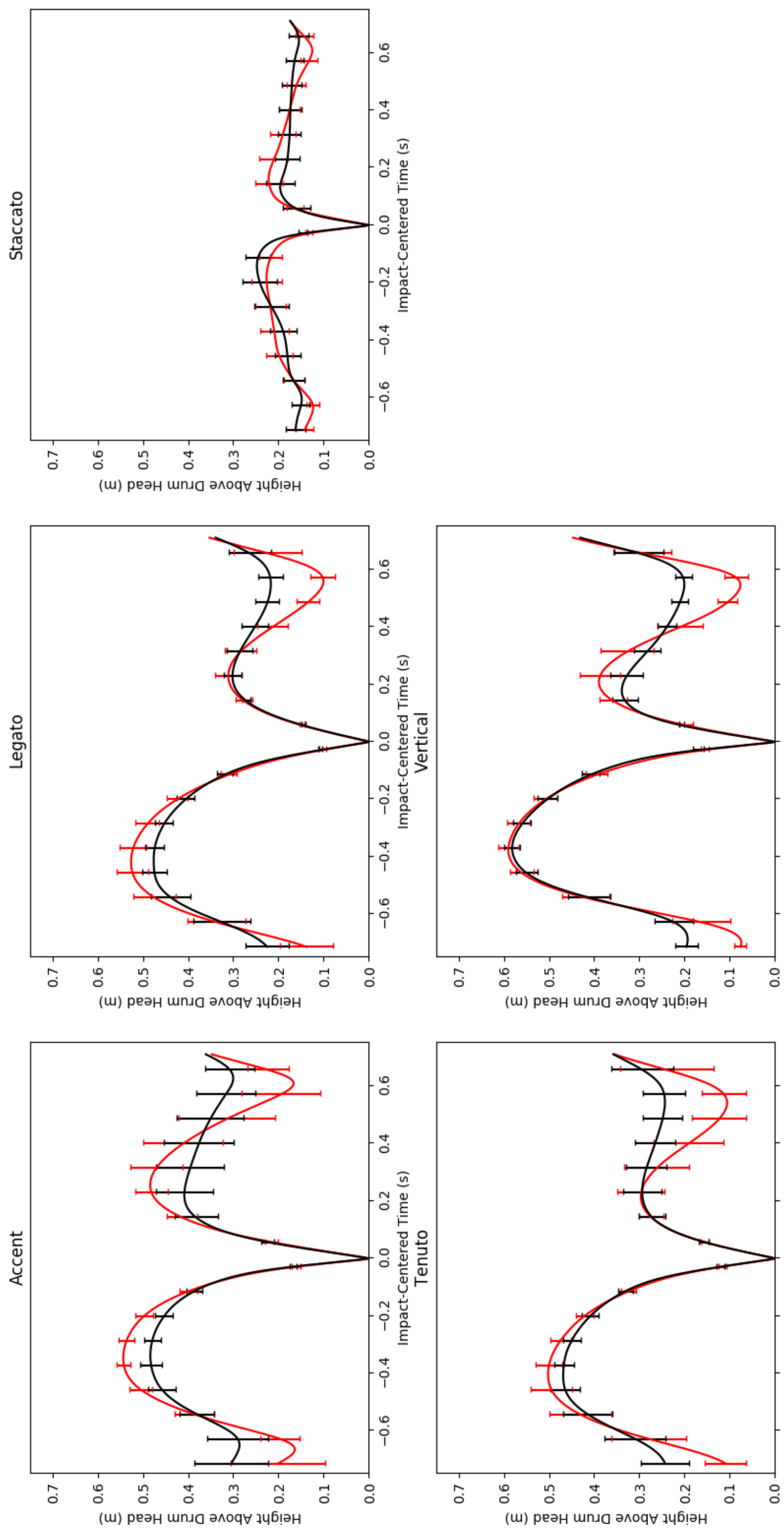


Fig. 4.1 Left 1 Average Trajectories with Standard Deviations red = dominant hand, black = non-dominant hand

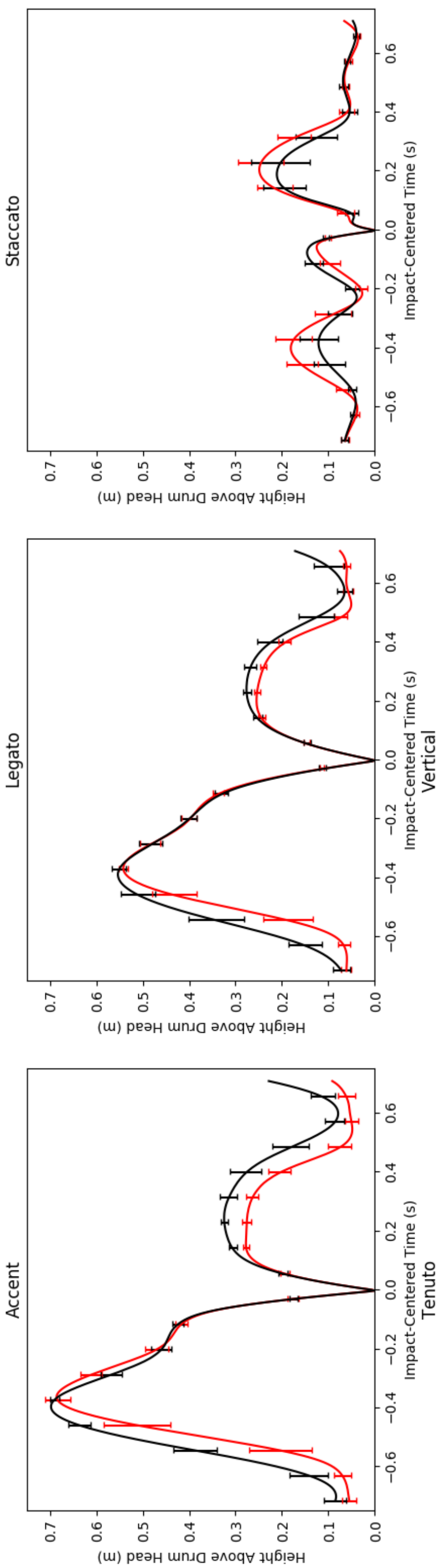


Fig. 4.2 Left 2 Average Trajectories with Standard Deviations
red = dominant hand, black = non-dominant hand

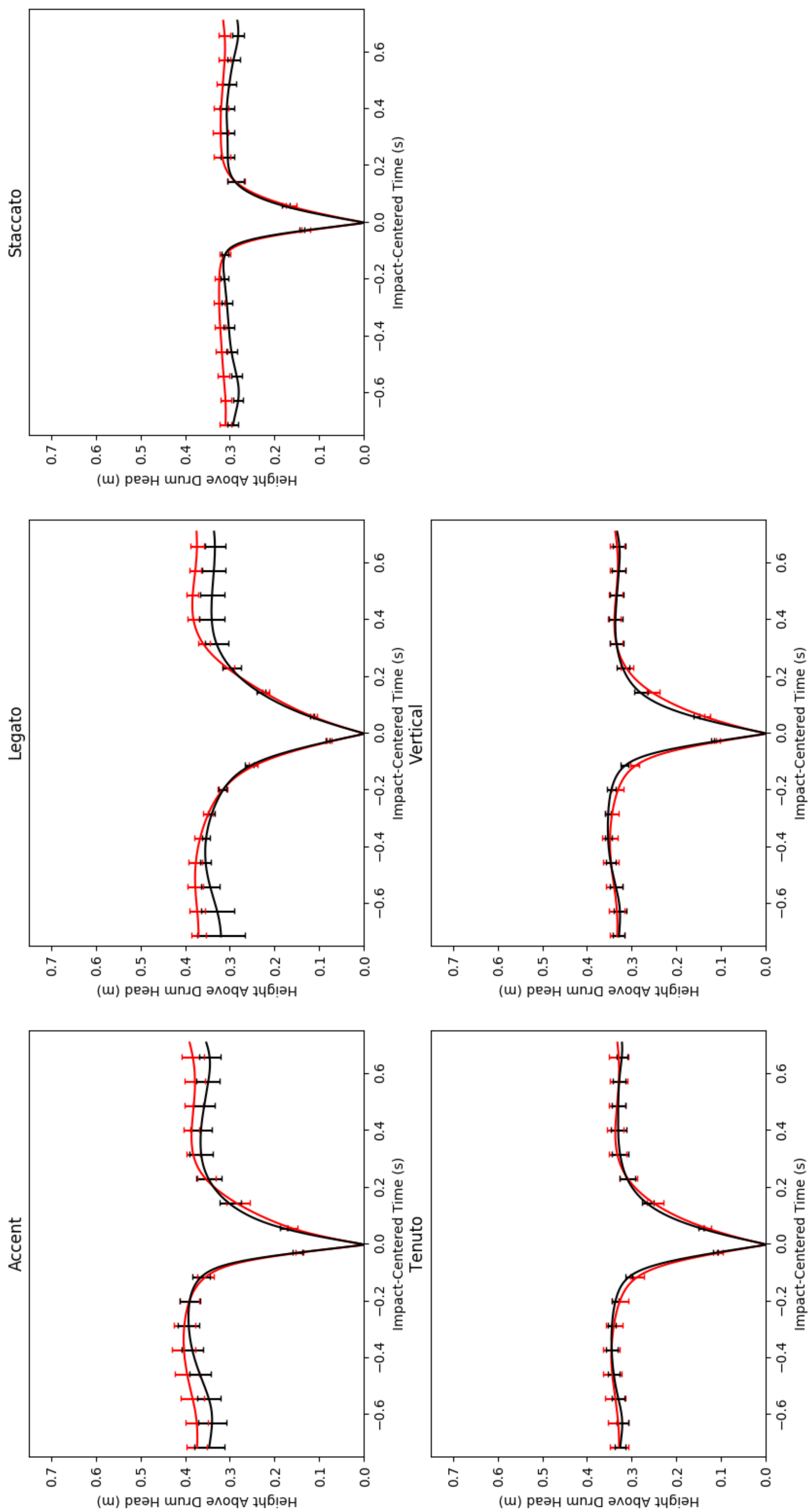


Fig. 4.3 Left 3 Average Trajectories with Standard Deviations
red = dominant hand, black = non-dominant hand

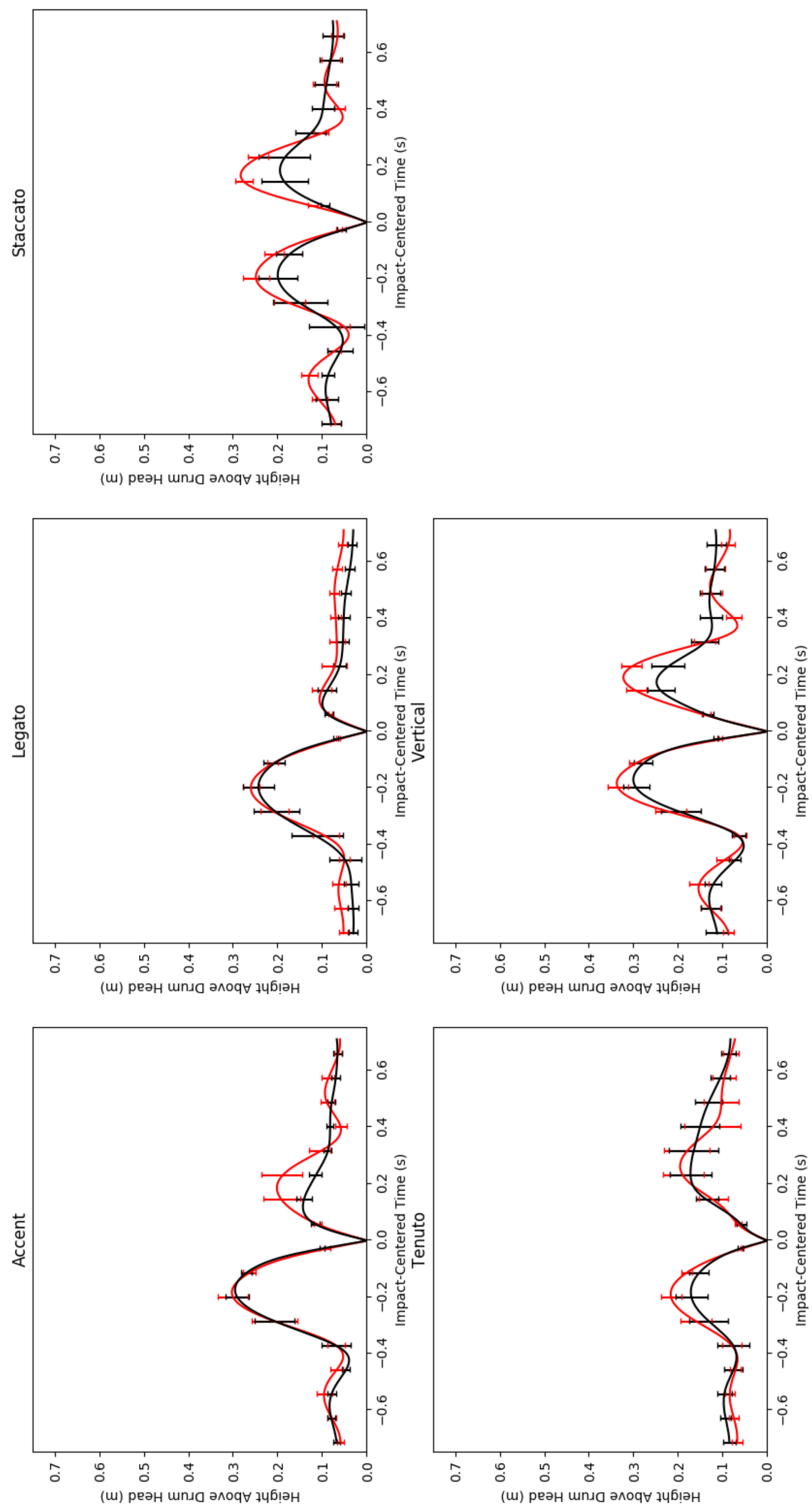


Fig. 4.4 Left 4 Average Trajectories with Standard Deviations red = dominant hand, black = non-dominant hand

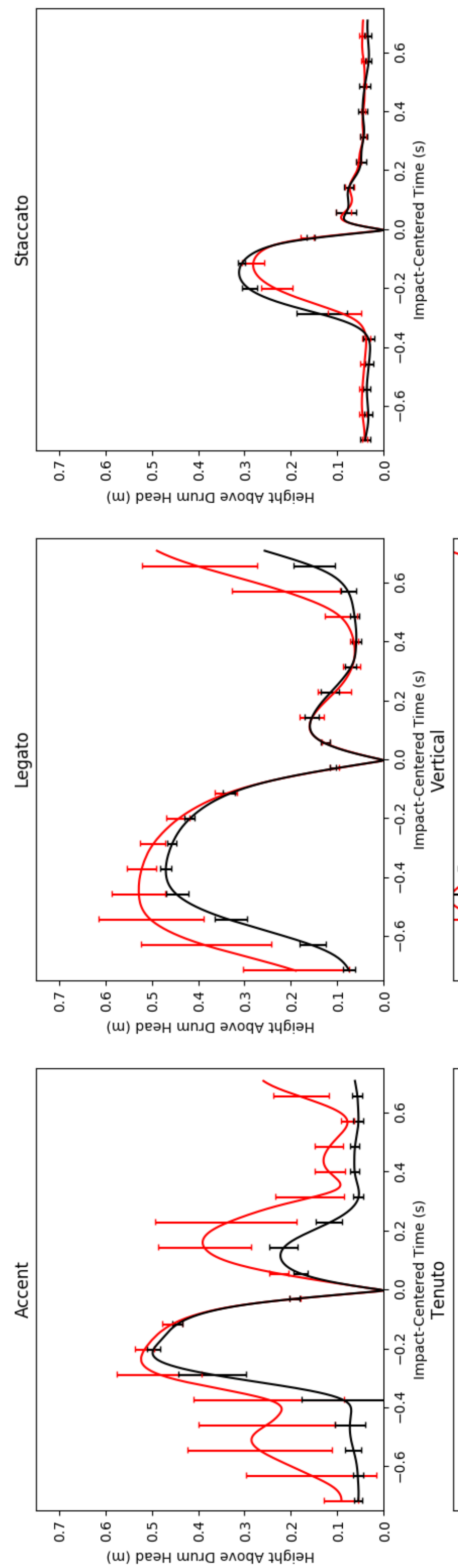


Fig. 4.5 Left 5 Average Trajectories with Standard Deviations
red = dominant hand, black = non-dominant hand

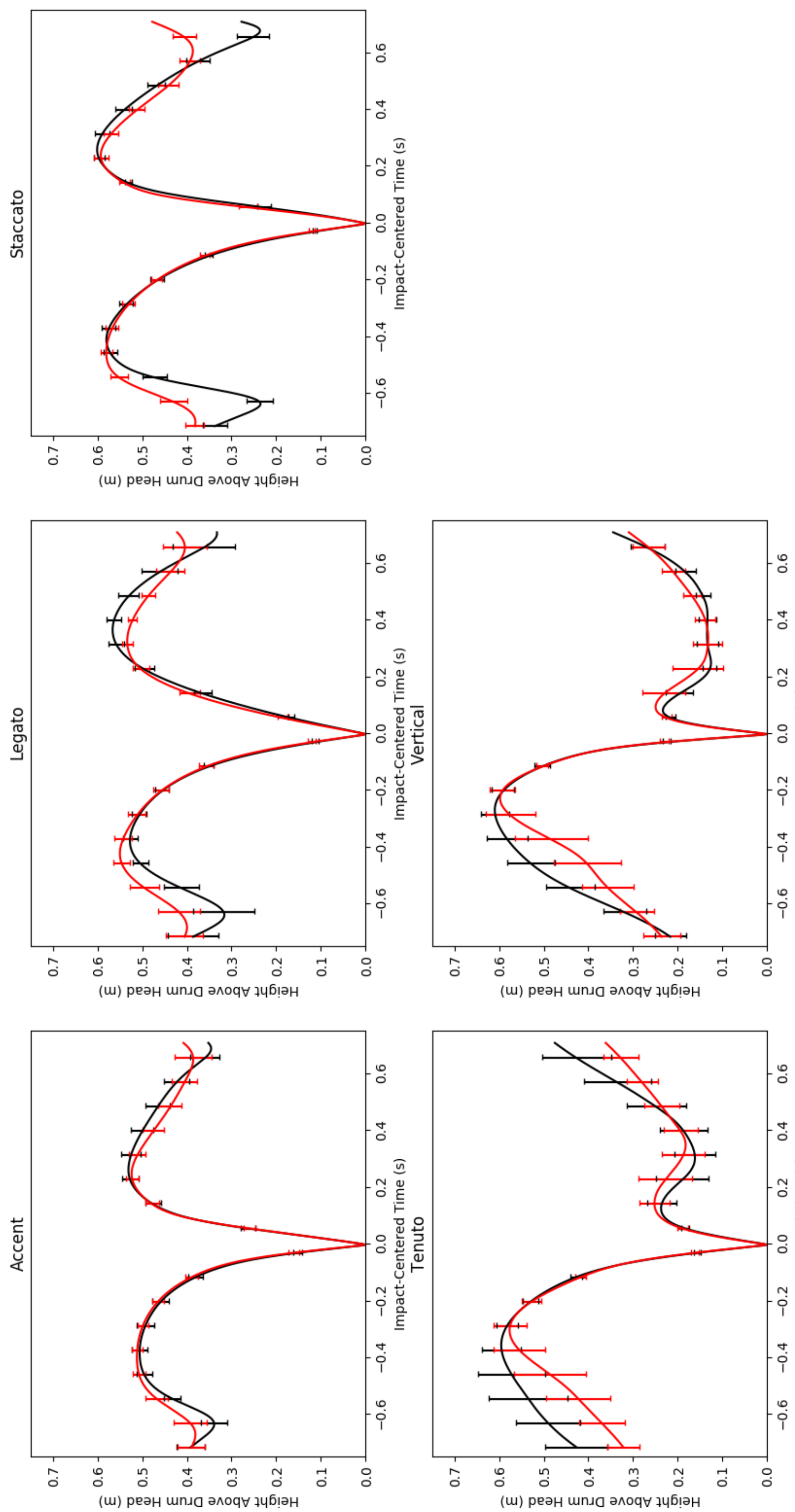


Fig. 4.6 Right 1 Average Trajectories with Standard Deviations red = dominant hand, black = non-dominant hand

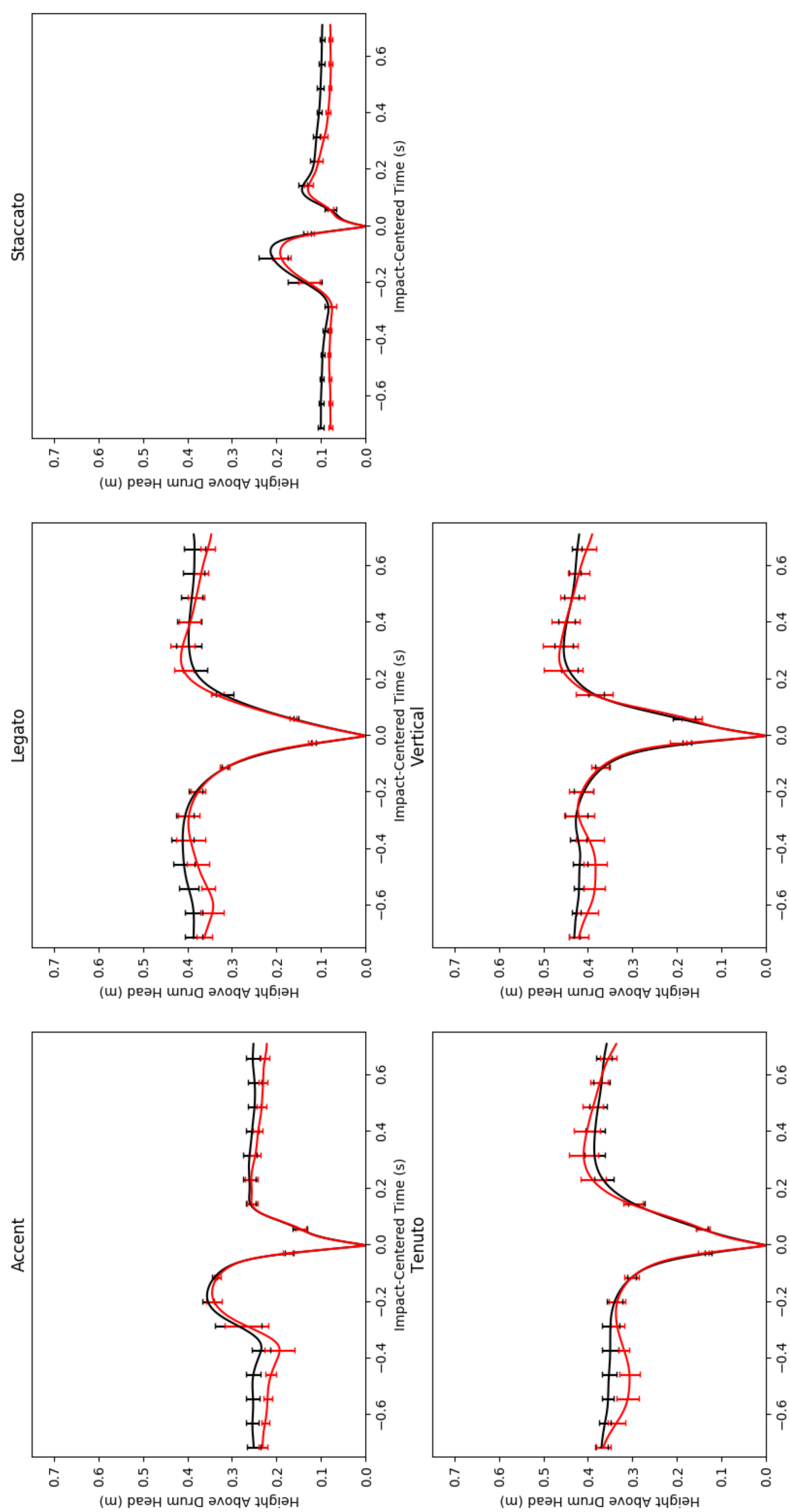


Fig. 4.7 Right 2 Average Trajectories with Standard Deviations
red = dominant hand, black = non-dominant hand

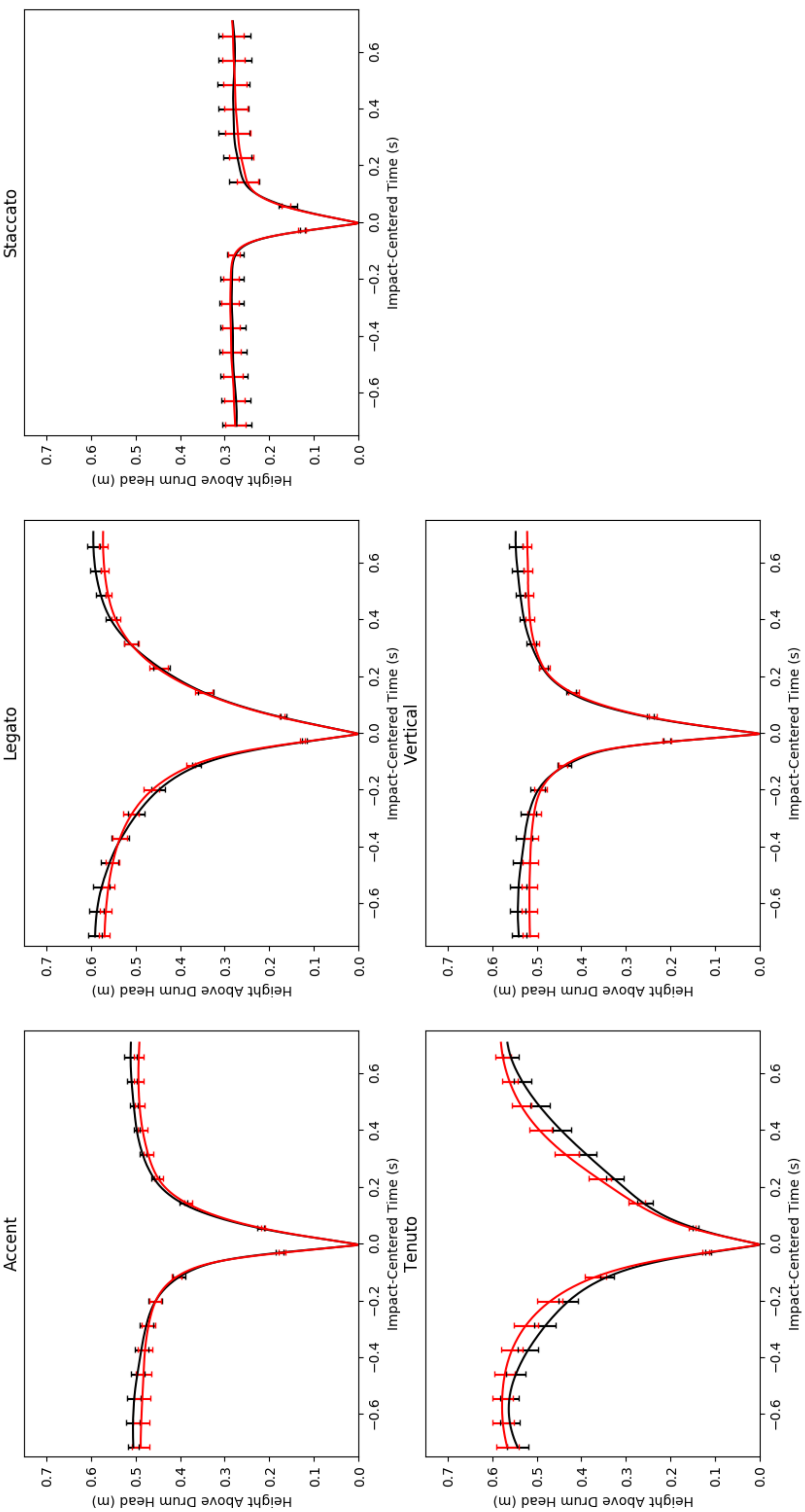


Fig. 4.8 Right 3 Average Trajectories with Standard Deviations red = dominant hand, black = non-dominant hand

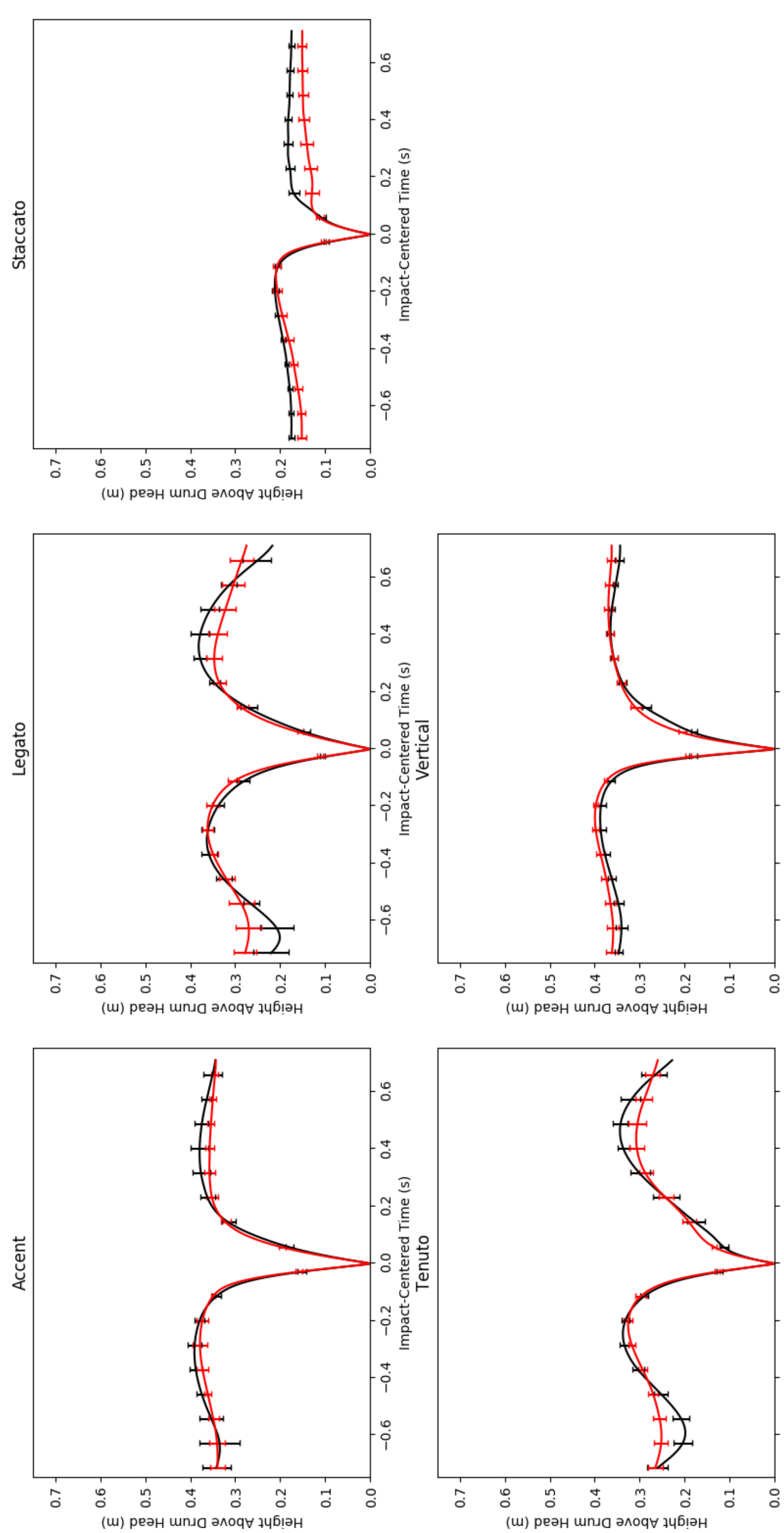


Fig. 4.9 Right 4 Average Trajectories with Standard Deviations red = dominant hand, black = non-dominant hand

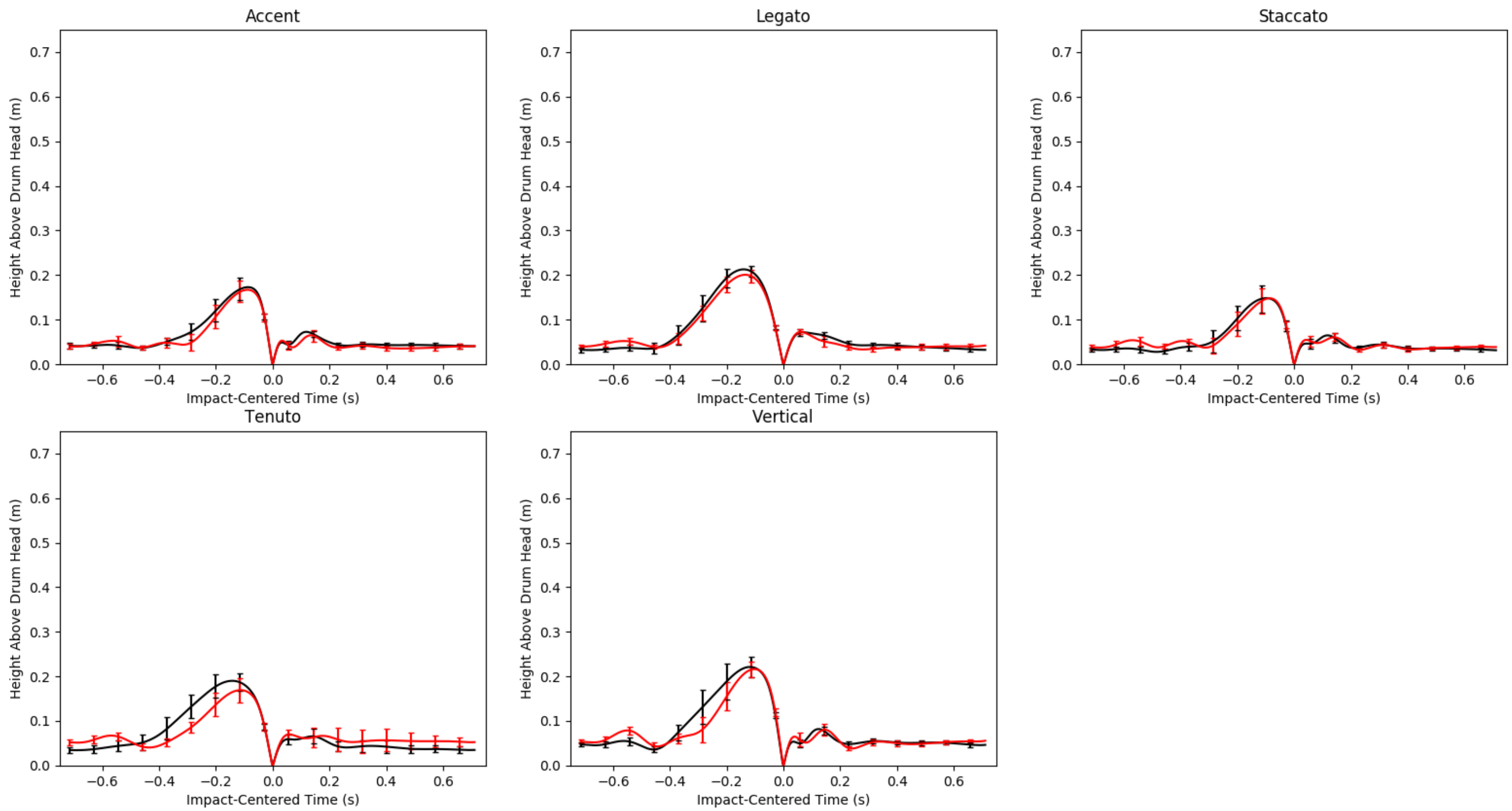


Fig. 4.10 Right 5 Average Trajectories with Standard Deviations red = dominant hand, black = non-dominant hand

Chapter 5

Conclusion

By reiterating the hypotheses and experimental results related to each hypothesis, this section serves as a comprehensive summary of the current findings. Hypotheses are presented in the same order they were addressed in the text: those that deal with functional differences between the hands followed by those concerning kinematic differences.

5.1 Experiment Overview

The experiment conducted for the current research consisted of two parts: the neutral task and the musical task. For both, percussionists were recorded using motion capture as well as video. The video was annotated and analyzed to determine which hand was used for each note in order to identify functional differences between the hands. Patterns in hand use were generalized into sticking strategies and were discussed in detail in Chapter 3. The motion capture data was used to analyze the mallet trajectories during the neutral task. Differences in trajectory (kinematics) related to each articulation and handedness were identified and reported in Chapter 4.

5.2 Functional Differences

This section highlights our first two hypotheses, as disccused in Chapter 3, to succintly highlight the results that were relevant as well as the final answer to each question.

Hypothesis: *Percussionists will initiate tasks with their dominant hand in accordance with their handedness.*

The human preference for a certain hand when performing different tasks was covered in depth in Chapter 2. There is little reason to expect percussion performance to be uniquely immune to the effects of laterality, despite percussion's emphasis on symmetry.

Bacon (2014) found that percussionists used their dominant hand for the first note when performing the musical excerpt and the neutral task exercise. In the current experiment, we confirmed these findings and the current hypothesis.

For both performances of the excerpt as well as all 5 trials of the neutral task, all percussionists except one initiated with their dominant hand. Left 1 was the only exception. While they began the neutral task trials with their dominant (left) hand, their use of right-hand lead during the excerpt performance caused them to start the exercise with their non-dominant (right) hand. These results raise questions about the effects of training on hand use in percussionists and require further investigation.

In addition to initializing with their dominant hand, all percussionists (except Left 1) played the final note of the musical excerpt with their dominant hand. However, this could be attributed to the fact that the final note of the excerpt falls on a downbeat. Given the preference for playing downbeats with their dominant hand reported in Chapter 3, this result is not particularly surprising. This could also be part of the reason the percussionists chose to begin the excerpt with their dominant hand as well as the difference in hand use of percussionist Left 1 between the neutral task and the musical excerpt. A different excerpt with a starting and final note that do not fall on downbeats would be beneficial to more fully explore the interplay between metrical importance and hand choice.

Hypothesis: *Handedness effects the choices a percussionist makes regarding the musical function of each hand while performing.*

Bacon (2014) showed that a correlation existed between dominant hand use and metrical importance during percussion sight-reading. However, due to the imbalanced handedness groups (7 right-handed, 2 left-handed) combined with the small number of left-handed players, only general trends could be noted (e.g. players tend to prefer their dominant hand regardless of handedness).

We sought to replicate the results by using the same musical excerpt. In addition, by utilizing equal-sized groups of right-handed and left-handed players, we were able to demonstrate differences in sticking strategy between the two groups.

As discussed in Chapter 3, both groups strongly preferred their dominant hand when playing metrically important notes like downbeats. This result indicates that regardless of handedness, a preference for the dominant hand can be observed when performing. However, the degree of dominant hand preference appears to be related to handedness. Right-handed players more strongly preferred their right hand than left-handed players preferred their left. The strong preference for the dominant hand found in the right-handed group, indicated by their handedness scores, may contribute to their uniform trend toward right-hand lead sticking. Since the left-handed percussionists were not as extreme in their hand preference, they may not gain the same benefits from relying on their dominant hand and were therefore more likely to use an alternative sticking strategy.

While these results are interesting, they represent only an initial foray into the topic of handedness and percussion. The small number of participants provides little statistical power. Future experiments should maximize the number of players to provide a more general view of handedness. However, the population of classically-trained percussionists is of limited size and the left-handed group even more so. In addition, in order to more clearly determine how degree of handedness affects playing strategy, future work should include a measurement of hand performance, like a tapping test, in order to gain a more quantitative measure of handedness.

Corollary: *The stickings used during sight-reading and the rehearsed performance would differ.*

Overall, stickings were fairly consistent between the two performances for each percussionist. However, specific trends did emerge with respect to adjustments made for the rehearsed performance.

The majority of players agreed more with at least one of the model stickings during the rehearsed performance compared to the sight-reading. This is likely caused by an increased reliance on training during the rehearsed performance. Since players were allowed to plan out their sticking, they utilized strategies that represent those that correspond to their training. Interestingly, the sticking strategy used by a percussionist appears to depend on handedness.

The right-handed group showed a clear trend towards a right-hand lead sticking strategy, with an average of 88.75% ($SD = 9.39$, $range = 73.96 - 96.87$) agreement with Model Sticking 1 for the sight-reading and increasing to 94.79% ($SD = 5.19$, $range = 87.5 - 100$) for the rehearsed performance.

The left-handed group was much less uniform, but all measured sticking scores increased between the sight-reading and rehearsed performance. Left 1, despite being left-handed, also closely followed a right-hand lead sticking with scores of 83.3% and 94.8% for the sight-reading and rehearsed performance, respectively. The results of Left 1 indicate that training greatly affects sticking strategy, so much so that natural inclinations due to handedness can be entirely inverted.

5.3 Kinematic Differences

This section deals specifically with the second pair of hypotheses covered in Chapter 4.

Hypothesis: *Mallet trajectory is sufficient to identify articulation.*

By extracting preparatory height and maximum striking velocity from the motion capture data, similar to Bouënard et al. (2008, 2010) and Chen et al. (2016), we were able demonstrate clear differences between the various articulations. Verifying these objectively with a machine learning algorithm like Bouënard or Chen is certainly possible but outside the scope of this work.

When comparing preparatory height between percussionists, *vertical* was highest on average for all but two percussionists. *Staccato* was lowest for the same number of players. Though *vertical* and *staccato* were clear outliers, the raw values of preparatory height showed little agreement between percussionists. Normalizing by the *legato*, or normal, value revealed that although players may play at different heights due to body size, the relative height for each articulation is similar across percussionists. In this study, the average *staccato* stroke was only 65% of the height of the average *legato* stroke. The left-handed group showed more variation in relative height for both the *vertical* and *staccato* stroke than the right-handed group. However, it is unclear if this is a systematic difference caused by handedness or merely an artifact of the small sample size.

In general, we would expect striking velocity to be directly correlated to preparatory height (Dahl 2011; Dahl and Altenmüller 2008; Dahl, Großbach, and Altenmüller 2011). While this is the case for the *vertical* articulation, *staccato* did not follow this trend. Despite being the smallest gesture by far for most participants, it usually fell in the middle of the five when considering striking velocity. By playing with short, fast movements, percussionists are better able to communicate that the audience should perceive the note as short. While initial research on marimba has shown that there may be no measurable difference between sounds created by different stroke types (Saoud 2003), further research is required to test this on timpani.

Hypothesis: *There exist systematic differences between the mallet trajectories of each hand.*

It has been shown that the trajectories of each hand during playing are not exactly symmetrical (Bacon 2014; Dahl and Altenmüller 2008). Interestingly, much of the current analysis showed no significant difference between the hands. This is likely due to the values that were measured in the current study.

Our results clearly show that analysis along a single dimension (mallet height) is not sufficient to expose clear differences between hands. However, the lack of differences is also noteworthy. Stick height is incredibly important in percussion performance, so results showing a high degree of similarity between the left and right hand indicate that the tenets of percussion training are effective in fostering symmetry of gesture.

5.4 Future Work

This work applies a *new school* approach, motion capture and numerical analysis, to an *old school* topic, percussion performance and specifically the effect of handedness. Ideally, this kind of research would allow for measurement and data-driven evalutation of the central tenets of percussion pedagogy. While these results shed new light, it is the opinion of the author that few generalizations can be made without an auditory component. Differences between the gestures required to perform different articulations are evident in the data. However, without measuring how these affect audience perception of the sound, little can be claimed. A multi-modal approach, auditory and kinematic, is required if researchers want to meaningfully change or reinforce classical percussion pedagogical strategies.

In addition, while having equal-sized handedness groups allowed us to directly compare sticking strategies, the relatively small sample size limits the scope of the results. Future studies could maintain the balanced number of each handedness while greatly increasing the number of players. This would allow for greater generalizability of results. However, the population of classically trained, left-handed percussionists is not large, so this may prove challenging.

The greater number might also allow for a more even handedness distribution. The present study had relatively extreme handedness scores with no players between -9.1 and +69.2. By including players of mixed handedness, we could more thoroughly investigate the correlation between sticking strategy and degree of handedness instead of merely grouping right-handed and left-handed players. In addition, a measure of hand performance would help clarify the effects of different degrees of handedness.

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