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Characterization of tea whisking by Japanese Tea Ceremony performers

Rogelio Isaac GARZA VILLARREAL

School of Knowledge Science
Japan Advanced Institute of Science and Techonology
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MASTER'S THESIS

Characterization of tea whisking by Japanese Tea Ceremony performers

1550016 Rogelio Isaac GARZA VILLARREAL

Supervisor: Professor Tsutomu FUJINAMI
Main Examiner: Professor Tsutomu FUJINAMI
Examiners: Professor Kazushi NISHIMOTO
Associate Professor Hideaki KANAI
Associate Professor Takaya YUIZONO

School of Knowledge Science
Japan Advanced Institute of Science and Techonology

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Chapter 1

Introduction

Human beings move all day, every day. It seems like a trivial subject to most due to the nature of it; it just happens. We have the ability to assess how difficult for us is the movements someone else is doing, to know within a matter of seconds if someone is better at dancing, for example, than other person. Nevertheless, putting this 'difference' into words is quite a hard task. Pinpointing the explanation behind a particular motion is not trivial.

Combinations of motions that produce a certain specific goal, motion skills, are of particular importance. Humans have created, developed, and shared physical skills for centuries. People strive to become better at them, whether it be playing musical instruments, performing a dance, or scoring a goal. For many years most of the secrets of these combinations of movements have been hidden in a dimension that is not easy to grasp by common means; they were simply too difficult to describe. But in the present day, thanks to computational techniques, more information can be obtained from the skills of the masters and be used for the advantage of new people that want to learn more effectively or even get to levels not achievable before. This is why the study of motion skills is relevant.

Japanese people have a particularly heavily tacit knowledge-dependent way of teaching their crafts to the next generations. As Kondo [10]n mentions, the mentality is that the body learns by doing and that the techniques just stick to the body. This is especially true in the traditional 'ways' of arts that follow a Zen ideology in its foundations. Calligraphy, flower arrangement, and karate, among others, have in common the ideas of incorporating both body and mind into the practice of their craft. Out of these, Japanese traditional tea ceremony stands as an interesting example of tacit knowledge, even being mentioned as so by Nonaka [15] and Takeuchi [4], who helped introduced such term. The honing of the skills of performers of the way of the tea will be our main focus in this research.

Traditional Japanese Tea Ceremony has been around for centuries and its practices, along with the characteristic motions that are related to them, have not changed much since the age of *Sen no Rikyū*. It has been the subject of a wide variety of research, from anthropology to gender studies due to its morphing role in society through the years. Nevertheless, not much attention has been put on the way the practitioners move or learn these motions. In the present research we change that.

1.1 | Research Approach

In this research we address the vacuum of research about the whisking skills of practitioners of the Japanese Tea Ceremony. We will, through motion capture techniques and statistical analysis, characterize the motions of practitioners while they are performing basic motions that can be observed when they take the role of the host of the ceremony. Furthermore, we will try to address the following questions and hypothesis while doing so.

How is the development of the practitioners over time?

Cha no yu, another way of calling the way of the tea, is thought by example from master to disciple over a long span of time. Techniques and rituals increase in volume and complexity as time goes by and one can attain grades for mastering a given number of ways of preparing tea. But, contrary to other physical skill-related activities like soccer in which anything goes as long as you score a goal (or avoid one against) or dancing in which rules are less defined, or even do not exist, Tea Ceremony has a set of rules from which is difficult to deviate from. These norms are decided by the *iemoto* (grand master) and his small group. [3] Although some freedom exists at higher levels, we expect that the tightness of the framework in which the skills are learned to converge strongly.

What is the role of body coordination in whisking?

As we will discuss in Chapter 2, other studies have looked into the coordination of body parts while performing a skill. We propose that coordination increases with time and the refining of the basic motions of the preparation of tea. In specific, we believe that masters, when compared to novices, will present a more stable hand movement that is produced by a few groups of body parts that move in unison. We also expect that the right and the left part of the body move at the same time as much as possible.

Do students of different teachers evolve differently?

We have established that we believe there is one ideal and that all performers to reach this stage. Nevertheless, it is not necessary that the road they take to get there is the same, especially at the beginning. We expect to see differences between novices, but believe they are defined by the teaching methods of their *senseis*. This would mean more similitude between two novices of the same school, even if this similitude is in wrong coupling of body parts.

1.2 | Motivation for the study

The present study serves to fulfill two purposes: shedding more light about the embedded information in the motion of the practitioners of *Chado* (The way of the tea) and to introduce a new activity to the attention of the skill science community. Japanese tea ceremony has, by its own will and nature, retained old teaching traditions that hide too much knowledge in the tacit domain. This has made recruiting new students harder as time goes by, because people nowadays, especially young people, do not have as much time and patience as before. We hope that this research will contribute to making learning Chado easier for new people.

Motion skill is a field that has been growing in recent years due to the increase of computational power and the appearance of new techniques. Studies have been done in a wide variety of activities such as the ones discussed in Chapter 2. Which this research, we wish to add Tea Ceremony to that list with the attention of attracting more people to research into this interesting activity from something different that the social sciences.

1.3 | Thesis Outline

This thesis consists of 5 chapters. On this Chapter 1 serves as the introduction and establishes the hypothesis, and the motivation behind this research. Literature review comes in Chapter 2 in which can be found a brief introduction to the Japanese Tea Ceremony. After that, similar work to this thesis will be discussed as it was taken into account for this research.

Chapters 3 and 4 are about the experimentation for this thesis. In Chapter 3 we describe the motion capture tool utilized in this research as well as the Plug-in Gait model that was applied to extract joint angles. We then discuss the logic behind the selection of the experiment, preliminary experiments, experiment setup, and introduce the subjects. The Chapter 4 focuses on results. We will analyze the data obtained from the experiment and discuss its meaning and repercussions.

The conclusion is in Chapter 5. In here we give our final thoughts about the successes and shortcomings of the research, as well as suggest future work that can be done in this topic. Appendices at the end contain graphics and tables that were not suitable for inclusion in the main text but may be of interest of the reader.

Chapter 2

Literature Review

In this chapter we present the story of the Tea Ceremony in order to shed more light about the relevance of this research. With the context set about the tacit knowledge sharing and the presence of the ideal for performers, we discuss several works that have influenced the present research.

2.1 | *Chado*: a brief introduction

In order to better understand the relevance of this research, a proper introduction of the Japanese Tea Ceremony is given in this section. The intention is to demonstrate the importance in Japanese modern society of the tradition, show some of its philosophy, and further explain the strong reliance on sharing tacit knowledge as the main channel of teaching. Finally, we share some important terminology that will be used on the rest of the document.

2.1.1 | History of the Japanese Tea Ceremony

Tea is believed to be originated in China [7] where the beverage preparation was first considered as an art. From there it spread to Japan, which would take this art one step further, making it almost a religion. Okakura in his classic essay "The Book of Tea" said that "The fifteen century saw Japan ennoble it[tea] into a religion of aestheticism,– Teaism." [16] But it was not until the sixteenth century that the way of the tea was born.

Towards the end of the Warring States period of Japan, there were several individuals that helped form the tea culture as we know it today. [18] Among them, Sen no Rikyū has been credited with the unification of different ways of performing tea ceremony [12] and his teachings continue to norm the main schools of chado. He, as much of the influential people of the period, was a believer of Zen Buddhism and much of its ideas can be seen in the practice of the following years. The concepts of *sabi* and specially *wabi* influence chado. Kondo [11] mentions the first refers to the beauty of the imperfect and the old, while the latter represents the beauty of simplicity and poverty.

After some political turmoil that resulted in the suicide of Sen no Rikyū, the wabi style of tea had a resurgence with his grandson Sotan. His sons inherited his teachings but decided to establish separate, although mutually friendly, schools: *Omotoesenke*, *Urasenke*, and *Mushanokojisenke*. These schools remain today as the ones with the most members, although several other traditions have spun-off from them. During the Tokugawa shogunate, several warrior tea masters led other traditions of tea ceremony that played an important political role.

The three Sen schools established an *iemoto*(grand master) system that meant that one family, and specifically one male head figure that "instututed new standards for training, accreditation, membership, practice, and even aesthetic taste." [18] After the Meiji restoration, the government gave importance to chanoyu because of its intrinsic Japanese cultural values and these civilian led schools adapted perfectly. At this point in time, it was still a somewhat elitist activity that started to refocus and integrate new members.

The twentieth century marked a distinctive change in membership with the opening to women to teach and a wider spread in society. [14] During World War II, due to the lack of men and money, the change was even more drastic, resulting with the female practitioners rising sharply. After the end of the war, chado continued to be a symbol of traditional Japanese culture that retains most of its Zen philosophy and aesthetic values and has spread throughout the country and the world. Nevertheless, this form of art that used to be reserved only for small groups of people in private situations is now also performed in front of large crowds, sometimes even for people outside the world of chanoyu.

2.1.2 | Teaching style of Japanese Tea Ceremony

The Japanese Tea Ceremony practice and the Zen Buddhism have been intertwined since the beginning of the modern era style of chado. Even though they are separate philosophies with different goals, some of the ideas overlap. In Zen, the master does not explain and instead lets the disciple figure out things by himself to reach enlightenment, believing that written words have no value [21]. Chado has since deviated from this idea and presently has a variety of textbooks and commentaries about the different rituals and tea preparation styles needed to improve as a practitioner. Nevertheless, the main source of knowledge acquisition is the tea room during practice.

The learning ladder is well defined in the Urasenke house of chado. The beginners have to learn the basic actions like sitting, standing, walking, folding the *fukusa* (a cloth to clean utensils), and whisking the tea for preparation. After grasping these concepts, the students start to learn tea preparation rituals, or *temae*. This is where the focus of the first years of the practitioner's life inside the world of tea learn. As this rituals are mastered, the knowledge of symbols and other philosophy is added. The experienced practitioners learn to take into account the different utensils used in Tea Ceremony to their basic actions and change accordingly.

The tea room becomes a place in which tacit knowledge can be shared from masters to disciples, and from experienced practitioners to freshers. It is said that the performance of tea ceremony is learned by watching, mimicking, and doing by oneself. The skill of each practitioner is developed through time by this process and cannot be bypassed by any reading or consumption of explicit knowledge of any kind. A starting student is expected to not question the master and instead simply do what told until the particular task is mastered. It is common to hear in practice utterances with no meaning unless they are followed of bodily actions to signal a different pattern of motion.

2.1.3 | Previous research done about Japanese Tea Ceremony

Japanese Tea Ceremony has been widely researched as a form of art, as a social thermometer and even as a religion [3]. Since Okakura [16] introduced Teasim to the west, occidental researchers have looked into the cultural role it has played in Japanese society. It has been used to represent the Japanese culture as a whole [19]. Nevertheless, the studies changed from a merely anthropological research to a social one.

It has been subject of women studies that analyze the shift of tea ceremony from a warrior only practice to an inclusion dynamic in the war and post war eras. [13] Another important element has been the aesthetic importance of the utensils that are used in the Tea Ceremony. [2] In recent years the experience of Tea Ceremony has been looked into, with even a suggestion that virtual reality might help learn the skill. [6] Nevertheless, there has been no research about characterizing the skill of the performers and we wish to address it with this research.

2.2 | An overview on the study of physical skills

The humans learn to produce different kinds of actions since they are born. Different tasks involve different periods of learning. Skill is developed through practice and usually takes time. Dancing, playing musical instruments, or even walking are actions that fall in this category. In this section we overview some existing works that have inspired this research. A common characteristic of these works is their focus on time series of actions in order to characterize and distinguish between subjects with different skill levels. Although the difference is not necessarily the most important part for some [5], we will focus on those who do.

Musical instruments and the skill required to handle them has been a recurrent topic of analysis for skill scientists. Ueno, Furukawa, and others have specially looked into the definition and characterization of cello players' actions. [8, 17] They focused on the characterization of simple closed motions by musicians of several backgrounds and analyze their data through several methods, such as angle changes and clustering. Results show a consistent difference between beginners and experienced musicians.

Skill is not limited to flashy actions. Clay kneading subjects were analyzed by Abe et al [1] through motion caption techniques. They discuss the differences of the skills of novices and experienced kneaders and look into the coordination phase of their movements. They found coordination and stable movement in more experienced subjects. Their phase analysis was an inspiration for this research. Yamamoto and Fujinami [20] continued the study and identified that there exists differentiation within coordination for closed actions with several body parts involved, suggesting that coordination is not the last step to master a skill, just a necessary one.

Everyday activities that might seem trivial are not so when looked into in detail. Noto and Fujnami [24] used accelerometers to analyze the action of cutting meat. A clear distinction between random and stable motions was found. Closed actions like this, even when they do not involve music, follow rhythms and patterns.

Another research that relied in accelerometers was Matsumoto's description of a samba group in which he looked into the differences in rhythm between beginners and their teachers. He analyzed data by looking into the patterns of repetition of the actions. He found that experience was related to repeating more consistently the same motion. [9]

All these researches have in common the analysis of time series of simple, closed motions of subjects performing a particular physical task. Several techniques have been used, and although the purpose is different for their works, some of them can be applied to our research. The concepts of coordination, synchronization, and balance are important to any research that tries to characterize actions such as whisking.

What these researches have in common is that they analyze actions that are not subtle or small, which is the case of preparing tea. In this research we look into preparing tea using techniques used in all of the above mentioned works. Motion capture was chosen over accelerometers or muscle sensors since they provide a finer degree of precision which is a crucial part. Nevertheless, positioning patterns, phase analysis and angle analysis are all relevant to the much finer and simpler motion that is whisking.

Chapter 3

Methods

In this chapter we discuss the experiment and its design. The first section talks about the tools and models used to record and analyze the data from the subjects. The second section describes the experiment design, including the description of the subjects, the process of calibration, and the data collection process. We also provide definitions that are useful to understand the results reported in Chapter 4.

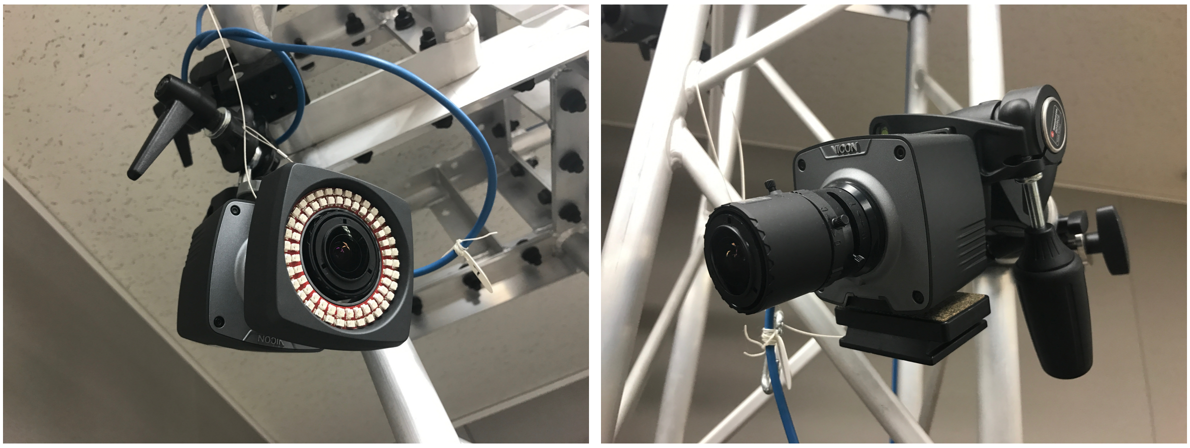
3.1 | Experiment tools

3.1.1 | Motion capture arrangement

For this research, a tool that could detect in to a fine precision the movement of the subjects that at the same time was not invasive and facilitated data analysis was necessary. In present day, motion capture systems that rely in markers and camera arrangements to identify their positions are reliable enough to be trusted with this task.

The camera arrangement consisted of eight optical cameras VICON Bonita B10 (Fig 3.1a) that were positioned in the corners and the middle of the sides of a square that was our area of interest. An additional VICON Bonita video camera (Fig 3.1b)was positioned in one of the corners that recorded normal images to compare to the data taken from the markers. This configuration allows for an accuracy of 0.5 mm[22] that allowed us to look into fine detail about the whisking of the subjects.

We used 9 mm markers provided with the system in the body parts of interest. In order to process the data of these markers we used the VICON Nexus 2.2 package. It allowed us to isolate the markers and visualize them in a three dimension space without any other information as seen in Fig 3.2. The package was configured so that three cameras would have to see a marker to recognize it and only two to follow its trajectory. Any gaps in the data were filled with the package pro-



(a) VICON Bonita B10 Optical camera (8) (b) VICON Bonita Video camera

Figure 3.1: Cameras used in the arrangement

vided solution. The subjects wore a special suit provided by the manufacturer that fits tight to the body and allows for the markers to be placed in the body as closest as possible to simulate an absence of clothes. Once the markers were hooked, they would rarely move from their position and thus we consider that all the changes in position registered are due to movements of the practitioners. The suit included gloves, shoes, and a hat for the head markers. They do not obstructed in any way the motion of the performers.

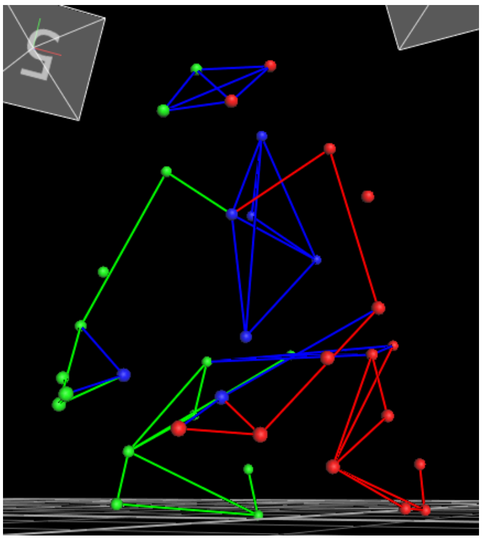
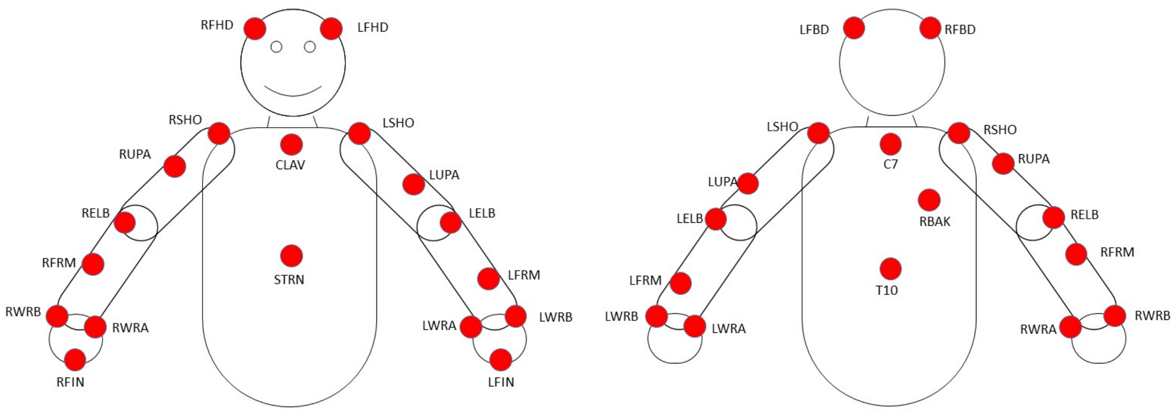


Figure 3.2: Markers for a subject while whisking as seen in the Nexus package

3.1.2 | Upper Plug-In Gait model

With the motion capture arrangement in place, a model was needed to mark the body parts and collect data. The VICON Nexus 2.2 package has installed the Plug-In Gait model that provides marker position and data analysis options. Although, as the name suggests, the model is mainly focused for the analysis of walking patterns, we found its upper body model satisfied our needs and decided to use it as is.



(a) Front View of Markers (b) Back View of Markers

Figure 3.3: Marker positions in the body used in the model

In Figure 3.3 we can find the marker positions for the upper body[23] that were used in the subjects for this experiment. The lower body markers were also utilized for the package to recognize the subjects and favor the labeling, but we made no significant analysis on them and are therefore not illustrated. This arrangement presents a unsymmetrical position for the upper arm and forearm markers and also has a single back marker on the right. These are markers used to distinguish from left and right in the model and are normally not necessary. Nevertheless, we opted to include them to obtain as much information as possible about the upper arm.

Another of the advantages of using the Plug-in Gait model is that it provides not only a marker arrangement, but joint angles that are calculated based on the data from them. Without the use of this model, the calculation of the angles would have taken more time. Most of the angles are calculated relative to their own axes and are thus not absolute. For this matter it is important to define the angles that are used in this research. They can be found in Table 3.1.

Angle	Name	Explanation
Shoulder Flexion	S Flex	The angle that corresponds to moving the arm straight forward or backward parallel to the thorax. A positive value means the arm is in front of the body.
Shoulder Abduction	S Abd	The angle that corresponds to moving the arm away from the body laterally. A positive value corresponds to an arm laterally moved to the center of the body.
Shoulder Rotation	S Rot	The angle that corresponds to having the arm rotate on its own axis. A positive value corresponds to an arm that is rotated to the inside of the body.
Elbow Flexion	E Flex	A positive value corresponds to a bent elbow
Wrist Extension	W Ext	The angle that corresponds to the hand moving towards or away from the palm. A positive value corresponds to the hand towards the palm.
Wrist Deviation	W Div	The angle corresponds to the hand moving towards the thumb or the pinky fingers. A positive value corresponds to the hand bending towards the thumb
Wrist Rotation	W Rot	The angle corresponds to the rotation of the wrist on its own axis. A rotation towards the thumb corresponds to a positive value

Table 3.1: Definition of selected angle outputs of the Plug-in Model [23]

3.2 | Experiment design

Our hypothesis proposes that Japanese Tea Ceremony practitioners develop a common behavior of motions as they progress to reach an ideal set by the grand master. In order to identify patterns in the actions, we decided to directly analyze the motions of performers of different skills and compare them in order to find similarities and differences. It was important to identify at least two groups, Novices and Masters, in order to find whether their actions match their practice time. This limits the amount of actions we can study, as novices do not have as much knowledge of *chado* as the more seasoned practitioners.

In order to select the motion that was to be analyzed, we asked subjects to perform some basic actions to identify which would be more suited for our research. Subjects used for this stage are all members of the Tea Ceremony Club in JAIST. They performed the actions described before and were timed. Four basic actions were considered for this experiment: sitting, standing, bowing, and whisking the tea. Bowing is important inside the tea world as it is done in different angles to show respect at multiple times during a ceremony, but is not an action limited only to *chanoyu*. This and the short time it takes to perform the action were enough reasons to discard bowing as our first attempt to look into the motions of Tea Ceremony practitioners.

Sitting and standing are actions that are similar but nevertheless different. There are clearly defined rules to them and are to be followed by all practitioners. They are also some of the first things thought to the novices. Although a strong candidate, it is an action that can be distinguished with plain eyes and takes a second to be performed. Patterns would be difficult to be identified with the technique we had chosen and therefore were discarded.

Whisking, or preparing the tea, had no problems with the time it was being observed. The motion is also simple and repetitive, which helps identify patterns. It is also a fundamental part of *chado* that cannot be found in other forms of arts or even of preparation of tea. It is an action learned since the beginning of the education of the practitioner as without it tea cannot be consumed. The preparation of a tea takes between 30 to 50 seconds to be finished, which provides enough time to collect data with the motion capture tool that can be further analyzed.

Another advantage of whisking is that it appeared to be a cyclical action. The hand of the subjects moved in what appeared to be a regular back and forth pattern above a well contained area defined by the tea bowl. With this considerations, whisking tea was chosen as the action of interest to compare masters and novices and test our hypothesis.

3.2.1 | Experiment Objective

The objective of the experiment is to characterize the action of whisking of a group of practitioners. The defined characteristics will be used to compare the performances individually and by group of skill. Lastly, it searches to identify coordination in body parts and its impact to the action itself.

3.2.2 | Subjects

For this research, seven subjects collaborated with us. They are all practitioners of the Urasenke school. Five of them belong to the Tea Ceremony Club of the Japan Advanced Institute of Technology (JAIST) and the other two belong to a circle in the city of Kanazawa, Ishikawa. They are separated into three categories: masters, intermediates, and novices. Masters are all certified teachers and are allowed to pass on the teachings. We consider novices subjects with less than two years of practice. One subject does not fit into these categories and has been labeled an intermediate. More details below.

- Masters
  - **Master S** has practiced tea for about 50 years, and has been a teacher for 29. Presently she has the grade of Associate Professor and is certified to teach all the forms of preparing tea. She started learning *chado* because she wanted to learn manners for work and started being a teacher because she got the degree to do it. She is the main instructor of the club in JAIST.
  - **Master M** started learning tea ceremony 33 years prior to the experiment and has a teaching experience of 15. She has the grade of Full Time Lec-

turer and can teach most, but not all, forms of tea ceremony. Started learning because there was a circle at her job and decided to teach because she was told to help. She is the assistant teacher at JAIST.

  - **Master S** decided to start studying *chanoyu* when her *ikebana* (flower arrangement) teacher decided to also teach it 40 years ago. She has been teaching for 20 years and is presently an Associate Professor. She has her own teaching place in the city of Kanazawa.

- Intermediate
  - **Intermediate S** has a 10 year history with the study of *chado* but has only been actively for 5 of them. She started because her mother also was a practitioner. She is part of the JAIST club and has been a regular for three years, participating in practice every two weeks.

- Novices
  - **Novice S** studied for a year, stopped for two and a half years, and then continued for another year. He decided to start studying because *chado* seemed to represent Japanese culture. He has spent the last part of his studying in JAIST. He practices tea ceremony twice a month, at best.
  - **Novice H** started the year of the experiment to study in the tea ceremony club in JAIST. His reason for participating was because of the recommendation of his older sister. He has been practicing tea ceremony every two weeks as part of the club activities.
  - **Novice A** has a year of study under Master S in Kanazawa. She decided to start practicing *chado* to learn manners and Japanese culture. She practices once a week in a more serious environment than the JAIST Club.

3.2.3 | Experiment Description

The experiment was conducted in four different sessions in between December 2016 and January 2017. Subjects were inquired about their time of practice and, in the case of the teachers, teaching the Japanese Tea Ceremony. After a brief explanation of the motion capture system, subjects were asked to change into the special suits provided to attach the markers in their correct positions. For the Plug-In Gait Model some bodily measures are needed, and were taken before introducing the subject in the system. The measures can be found in the appendices in Table A.4.

Figure 3.4: Tea bowl and *chasen* used in the experiment

The calibration routine was divided in two different takes. The first involved the subjects standing for five seconds with their arms open in a T shape. The second take started like the first one but continued with 30 seconds of free movement, although subjects were encouraged to move their joints as much as possible. This calibration step is necessary to conduct the experiment. When the system recognized the markers automatically, the data collection started.

Subjects were asked to prepare a bowl of tea while being recorded by the motion capture system. The tea bowl and the whisk shown in Fig 3.4 were used in all the takes, but each subject decided the amount of *matcha* powder and boiling water to be used each time. Each subject was asked to produce bowls three times. In order to reproduce the action as close as possible, each time subjects were asked to perform the motion starting from taking the whisk from the floor and ending with presenting the tea bowl to the guest.

Figure 3.5: A subject during data collection

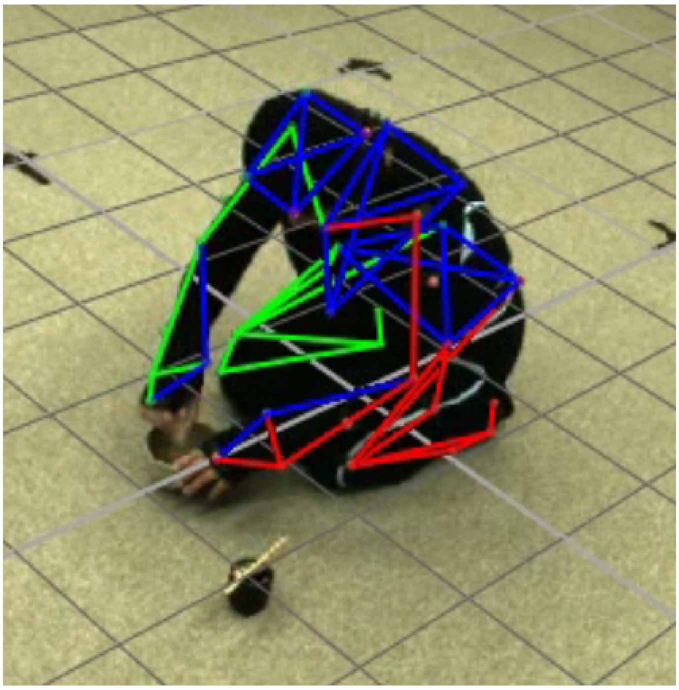


Figure 3.6: A subject during data collection with the marker analysis supperposed

Chapter 4

Results

In this Chapter, we analyze and interpret the results of the experiment described in Chapter 3. In Section 4.1 we look into the position of the body parts that are involved in the process of whisking and compare its properties between subjects. Section 4.3.1 focuses on the angles in the joints of the right hand and the possible coordination between actions. To end this chapter, we summarize our results and discuss the difference and similarities between whisking techniques of the subjects.

4.1 | Positions of body parts

To analyze an action it is essential to identify the body parts that are most relevant to the movements observed. In the case of whisking, it was clear from the beginning that the right arm was of importance, but whether other sections of the body of the subjects also moved when preparing tea. In order to identify the relevant time series to our research, we observed the positions of all the position markers in the upper body according to the Plug-In Gait Model described in Section 3.

We analyzed the behavior of the markers in the upper body and recorded the standard deviation of the position for all markers (Tables A.1, A.2, and A.3 in the Appendix). The right arm of all subjects was the body part with the bigger variation during the chosen time frames, with the standard deviation being bigger than 3 mm in most cases and sometimes even surpassing 10 mm for the RFIN marker. The other arm contrasted as most subjects had a standard deviation of under 1 mm on all the markers positions in all three coordinates. This is because it is used to hold the tea bowl so that whisking is easier to perform.

We had identified that the right arm moved and the left did not move without checking the data, but it was unclear if the back had any role in the action of whisking. The posture and balance of the column are important in Tea Ceremony, and for whisking they appear to be under control. All subjects present less than a millimeter of standard deviation on the markers on their column. The same can be said for the markers in their chest. With this result we arrived to the conclusion that they do not move enough to make an impact or characterize the whisking action in any particular manner.

The head markers are the only body part that has bigger variation in the three axes. Nevertheless, as the thorax does not move, it means that is a motion not related directly to the whisking but rather small adjustments to better perceive the contents of the tea bowl. The result of this analysis leads us to further look into the motions of the right arm as our area of interest.

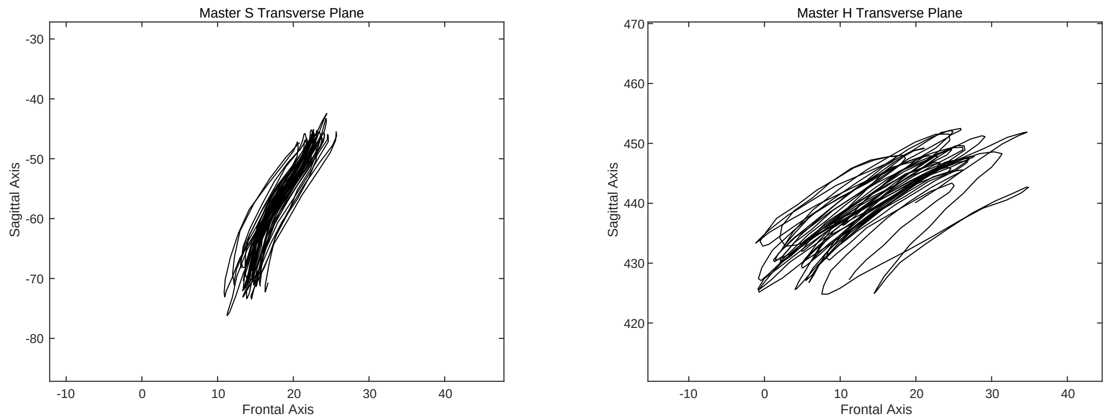
The position of the RFIN marker is of particular importance to our research. It sits roughly on the top of the chasen and is can be considered the guidance point of it. It is also the point that practitioners see while whisking and the one they consciously control. For this reason, we will look at upper body positions in general and the changes in position of RFIN in particular to asses differences between Masters and Novices.

The motion capture system provides data for the absolute positions of the markers in the reference frame of the room it is calibrated in. All data is in millimeters. In order to locate the most relevant data, we have selected time series of 500 frames of length in each case that represent the most stable action of whisking of each subject. To compare the actions of different subjects, we will analyze them by planes in the next subsections.

4.1.1 | Transverse Plane

The transverse plane is defined as the plane that divides the body in two that is parallel to the floor. In the coordinate system used by the VICON Nexus system, a graph in this plane is an X vs Y coordinate representation of position. They correspond to the Frontal Axis and the Sagittal Axis respectively. This is the plane that is perpendicular to the view of the practitioner when preparing tea. It is the only plane that gives them information about the tea present status and their progress in the preparation.

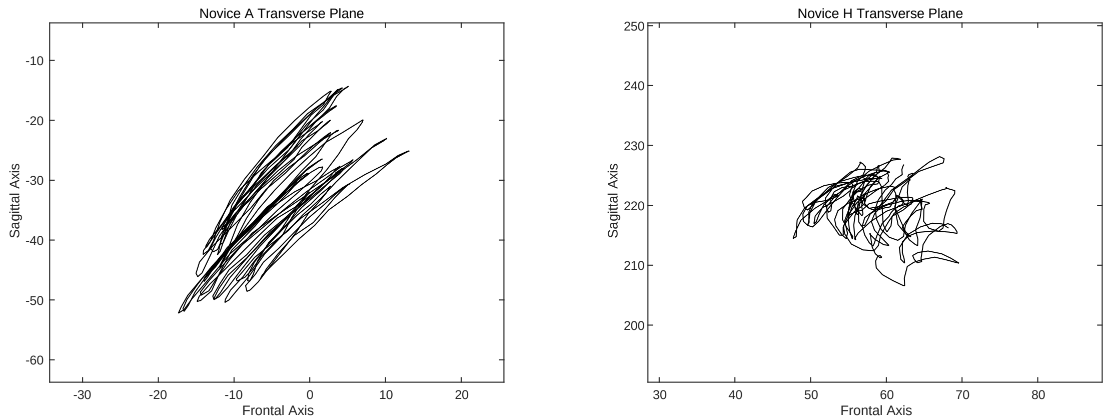
The Master group of subjects present similar characteristics in their plots. They are diagonal lines with a significant positive correlation. This indicates that the



(a) Master S (b) Master H

Figure 4.1: RFIN positions in the Transverse Plane of Masters

chasen is more likely to travel on the same line as seen from the top of the tea bowl. Master S (Fig 4.1a) has the most consistent movement among all subjects, with almost no deviation from the same path. The slight off-set we see in Figure 4.1b might be due to an adjustment to incorporate powder that was not being mixed properly. She nevertheless returns to her original path and continues over it.



(a) Novice A (b) Novice H

Figure 4.2: RFIN positions in the Transverse Plane of Novices

The Novices and the Intermediate on the other hand, have no path to follow. Novice A, as seen in Fig 4.2a, presents more of a back and forth motion, even though it is never on the same path. The same can be said about Intermediate S, as she has back and forth motions, but they are not always parallel to each other. Novice A seems to drift to the top and Intermediate S drifts to the left. The other two novices have no visible pattern. They ramble around one point instead of following a straight line. We can observe that in Fig 4.14b that shows an erratic, compact motion about the center.

Subject	Correlation
Master S	0.9543
Master H	0.7997
Master M	0.9598
Inter S	0.6704
Novice A	0.7893
Novice S	0.2119
Novice H	-0.0991

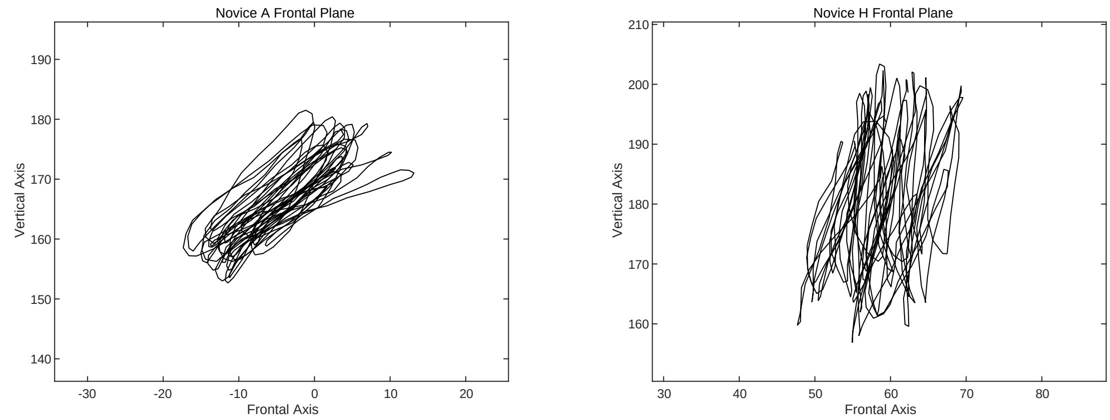
Table 4.1: Correlation value of the positions in the Transverse Plane

Table 4.1 sheds more light about the actions in the Transverse Plane. Novices S and H have no significant correlation between the time series in the Frontal and Sagittal axes. Intermediate S, Master M, and Novice A have similar low values of significant positive correlation. Nevertheless, the path that the end of the chasen follows in each case is quite different, the Master deviates and returns to a diagonal straight line, while the other two seem to drift. The other Masters have a consistent, almost complete correlation that shows that they follow only one path.

The rest of the plots of RFIN in the Transverse Plane can be found in the appendix A.1.1.

4.1.2 | Frontal Plane

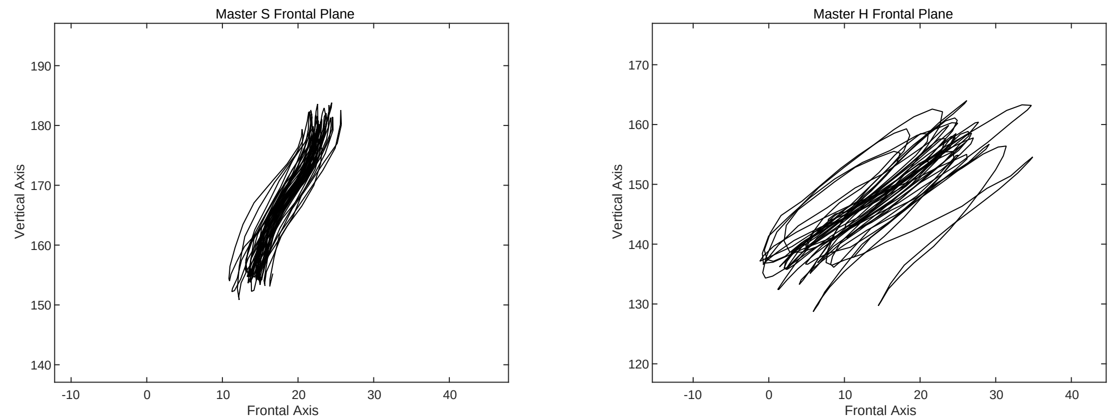
The frontal plane is defined as the one that divides the body in anterior and posterior and is perpendicular to the floor. In the coordinate system used by the VICON Nexus system, a graph in this plane is an X vs Z coordinate representation of position. They correspond to the Frontal Axis and the Vertical Axis respectively. This is the plane one would see if standing in front of the person performing, as the plane name suggests.



(a) Novice A (b) Novice H

Figure 4.3: RFIN positions in the Frontal Plane of Novices

There are more similar plots in this plane, when compared to the one in the last subsection. Novice H (Fig 4.3b) and Novice S have predominant vertical paths that contrast with motions of the other subjects. However, they are not as dissimilar as the ones in the Transverse plane. Novice A has a compact and regular pattern in Figure 4.3a that is closer to the group of the Masters than to the Novices. The same can be said for Intermediate S.



(a) Master S (b) Master H

Figure 4.4: RFIN positions in the Frontal Plane of Masters

Master S has a very well defined path that is slightly curved (Fig 4.4a), in contrast with the more straight paths of Master M and Master H (Fig 4.4b). It is worth noticing that Master M and Master H have been practicing together for a long time, while Master S has received training elsewhere. This is relevant for out hypothesis that proposes that, although an ideal is being pursued, the day to day training and exchange of tacit knowledge has more weight in the practitioners over time.

Subject	Correlation
Master S	0.9441
Master H	0.8165
Master M	0.7173
Inter S	0.3931
Novice A	0.7940
Novice S	0.1730
Novice H	0.3690

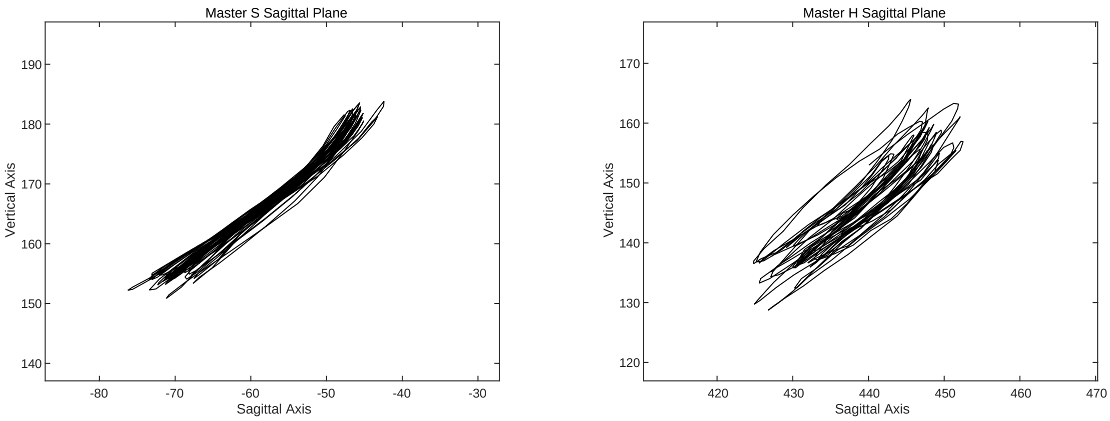
Table 4.2: Correlation value of the positions in the Frontal Plane

The correlation values for each subject in the Frontal Plane is given in Table 4.2. In this case we see that the Master group of subjects again present a high significant positive correlation, which indicates that consistency is present in their actions. Novice A has also a high value, which suggests her whisking is closer to that of a Master that to that of the Novices. The rest of the subjects have no significant correlation in their X vs Z positions, suggesting that they have no definite path to follow.

The rest of the plots of RFIN in the Transverse Plane can be found in the appendix A.1.2

4.1.3 | Sagittal Plane

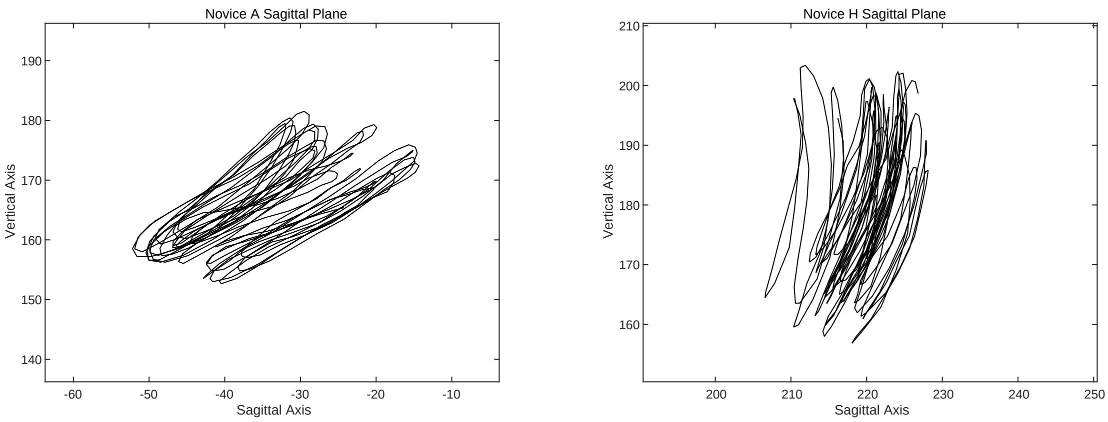
The sagittal plane is the imaginary line that crosses the body from back to front, dividing it in left and right and thus is perpendicular to the floor. In the coordinate system used by the VICON Nexus system, a graph in this plane is an Y vs Z coordinate representation of position. They correspond to the Sagittal Axis and the Vertical Axis respectively. When looking at the performer from the side, we are looking at this plane.



(a) Master S (b) Master H

Figure 4.5: RFIN positions in the Sagittal Plane of Masters

Masters have a stable path in this plane. Again Master S has little deviation from it, as seen in Fig 4.5a and present a similar range and domain to that of Master H (Fig 4.5b). Master M has a wider domain, but maintains her path along the whole action. So far, the masters present the same characteristics and seem to have similar tendencies, in line with our hypothesis, which is a positive sign, although not definite to make conclusions.



(a) Novice A (b) Novice H

Figure 4.6: RFIN positions in the Sagittal Plane of Novices

For this plane most subjects seem to have an identified path that they stick to in a regular basis. In Fig 4.6b is where Novice H shows the most consistent path out of his plots. Novices A seems to follow two paths during her motion, as there are two groupings that are parallel to each other in Fig 4.6a. Intermediate S and Novice

S also present a more stable and consistent path in comparison to their other plane plots. The back and forth action of whisking is responsible of this, as it dominates the influence on the position of the end of the chasen over the position of the hand itself.

Subject	Correlation
Master S	0.9854
Master H	0.9053
Master M	0.8109
Inter S	0.6943
Novice A	0.6354
Novice S	0.8887
Novice H	0.4086

Table 4.3: Correlation value of the positions in the Sagittal Plane

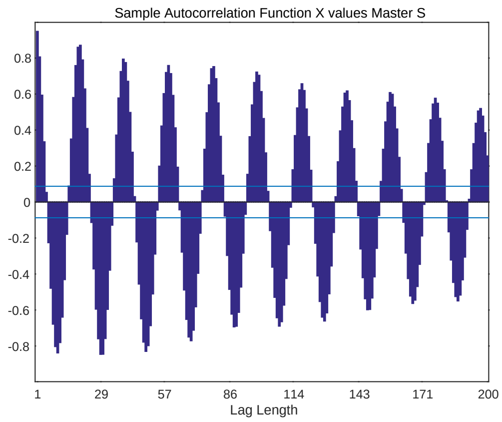
In line with the observed plots above, the correlation values seen in Table 4.3 are all positive significant correlations, with the exception of Novice H that is below a 0.5 threshold for significance. Novice S presents a much improved correlation in this plane when compared to the previous, and this can be explained in that his path varies widely in the X axis but is well defined in the other two coordinates. Novice A is the only subject that shows a significant decrease in correlation, due to her two paths instead of one as seen above.

The rest of the plots of RFIN in the Sagittal Plane can be found in the appendix A.1.3

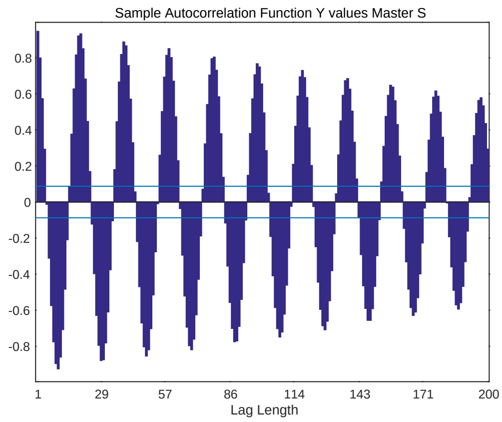
After analyzing the time series of the position in the three planes of motion we have identified a difference between Masters and Novices to some degree. The notion of a path that is followed by the whisk arises. With time and practice, practitioners develop a distinct path for their motions that is different for each performer but is constant in their movements. While they can deviate from that path, as we see Master H do clearly on the Frontal axis, they tend to return and converge in one constant, stable course. On the other hand, Novices have not developed yet their own consistent track and thus present a more erratic pattern of action.

4.2 | Identification of repetition in the action

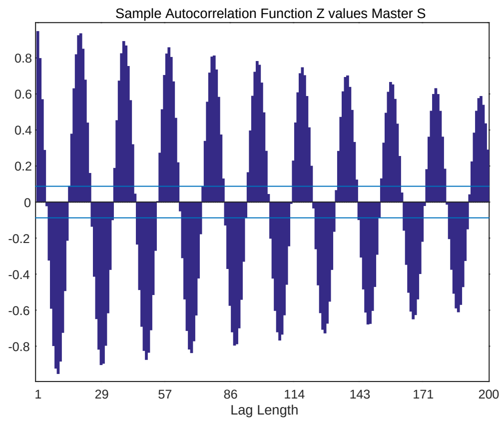
Whisking is a seasonal action. The hand and therefore the chasen travel in a back and forth motion and are limited to the area of the tea bowl. After we identified that the Masters follow a path that is mostly a straight line in three dimensions, it was of interest to see how the time series behaved when compared to itself to better understand the action. For this purpose, we analyzed the time series of the same 500 frames used in Section 4.1 for the three coordinates separately for all the subjects. We applied an auto correlation function to each data set with 300 lags to identify possible repetition in the time series.



(a) Frontal Axis



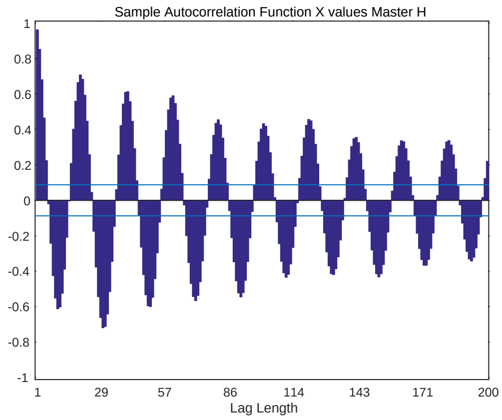
(b) Sagittal Axis



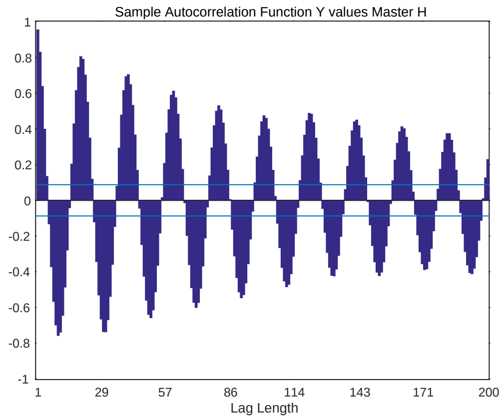
(c) Vertical Axis

Figure 4.7: Sample Autocorrelation Function plot for Master S

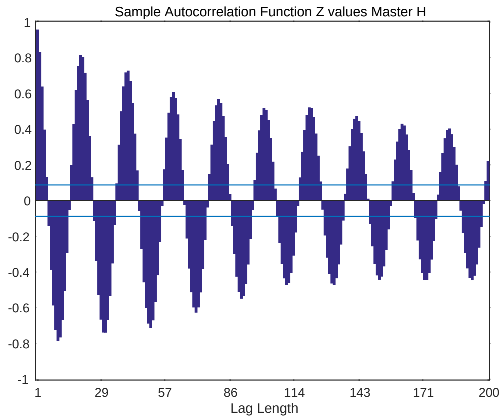
All the time series are clearly non stationary, but this can be tolerated for the qualitative interpretation we are giving to the plots. They have a tendency to zero as the number of lags increases, indicating that the more time passes, all the subjects change their paths even if it is slightly. Nevertheless, there are considerable differences in the behavior of the plots for the Masters, the Intermediate, and the Novices.



(a) Frontal Axis



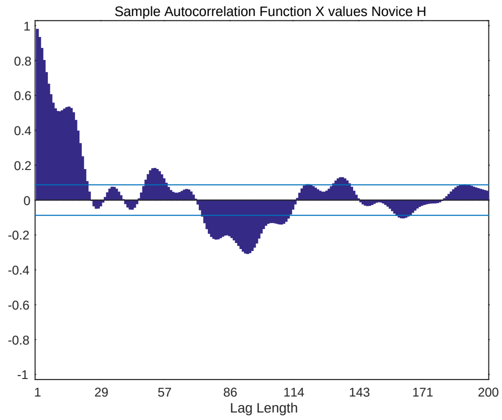
(b) Sagittal Axis



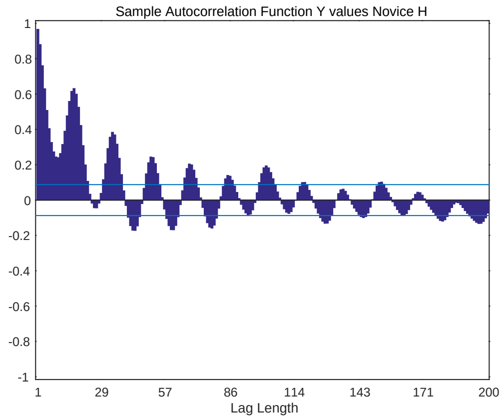
(c) Vertical Axis

Figure 4.8: Sample Autocorrelation Function plot for Master H

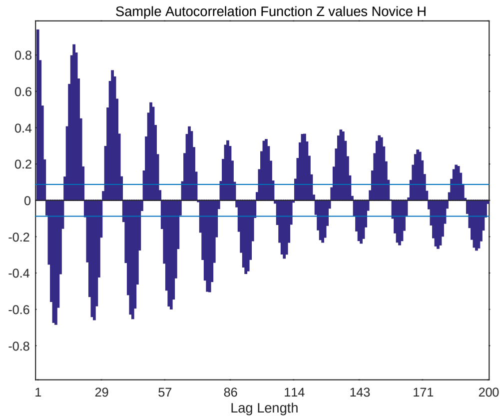
As we can see with Master S (Fig 4.7) and Master H (Fig 4.8), the time series of all three coordinates are similar to themselves if the lag is small. This correlation decreases with bigger lags. The result indicates that, although there exists a small drift, the phase remains more less the same as the amplitude of the sinusoidal shaped function decrease by the same rate of change. The maximums represent when the lagged signal is in phase with itself in n lags before, where n is the value in the horizontal axis. The minimums indicate antiphase. The reason the peaks of the plots of Master H decrease faster than the ones of the other Masters can be attributed to the small deviation from the path that we identified in the last section. Nevertheless, we can say that all Masters have a constant frequency along all the axes that result in similar plots.



(a) Frontal Axis



(b) Sagittal Axis

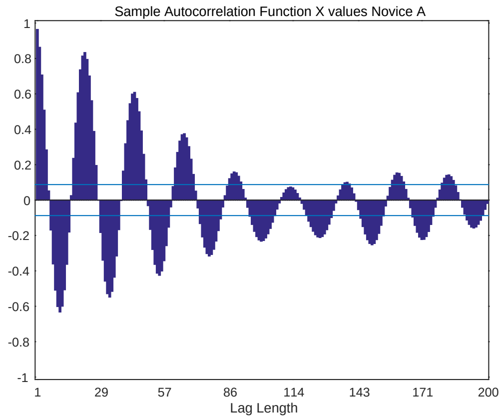


(c) Vertical Axis

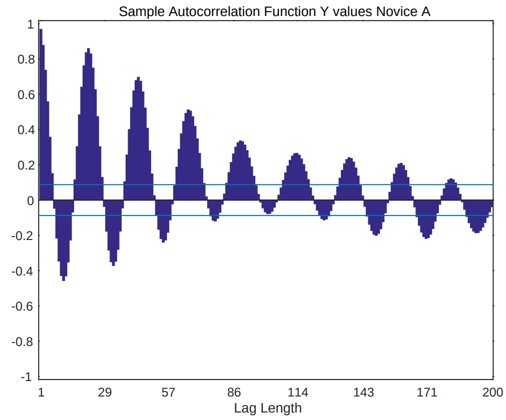
Figure 4.9: Sample Autocorrelation Function plot for Novice H

Novices, on the other hand, do not present the same characteristics in their plots. The auto correlation functions for the Vertical and Sagittal Axes of Novice H (Fig 4.9) are completely different and present no similar characteristics between them. Fig 4.9a is not a sinusoidal type of function and sharply decreases below the mark of significant auto correlation values and stays inside it. This indicates that his movements in the Frontal plane follow no significant cyclical pattern. In other words, his movements to the left or right are not repeated throughout the observed sample. The Sagittal Axis presents the form that would suggest a seasonality in the action, but again decreases quite fast and the distance between peaks is not regular.

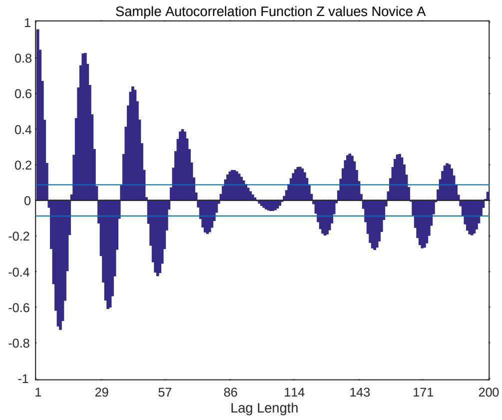
For the vertical motion in Fig 4.9c we observe a sinusoidal function inside another one that also appears to converge to zero. This is the most similar plot for him compared to the Masters.



(a) Frontal Axis



(b) Sagittal Axis



(c) Vertical Axis

Figure 4.10: Sample Autocorrelation Function plot for Novice A

The Figure 4.10 shows the data analysis for Novice A. In her case, there is a clear sinusoidal function in all of the plots, but they behave differently when compared to the Masters' ones. In the Frontal Axis (Fig 4.10a) the function decreases rapidly and remains low when increasing the time lag. After the 86th lag the function is no longer evenly distributed above and below zero, indicating that it spends more time being in antiphase than in phase. The contrary is true for the Sagittal Axis, as the positive values are bigger. For a cyclical movement we expect the same amount of peaks in the positive and the negative side with the same values. Novice A does not have a sinusoidal motion in any of the three coordinates, which suggests that she has not a well defined path, or center of a track that is followed during the action of whisking.

Masters and Novices have different patterns in their Auto Correlation Functions. Masters seem to have a better control of their Frontal Axis than their students. The more experienced the practitioner, the more evident it is that their motions are cyclical. Nevertheless, all the subjects present a decline, whether it be slow or fast, to converge with zero. This can be attributed to the small differences in movement in the human body and is expected to some degree. It does not clash with our notion of a path that is followed, as not all movements are made with the same amplitude on the same exact spot. It is worth remembering we are measuring in a domain in millimeters, so small variation is expected.

The plots for the other subjects can be found in Appendix A.2

4.3 | Joint Angles

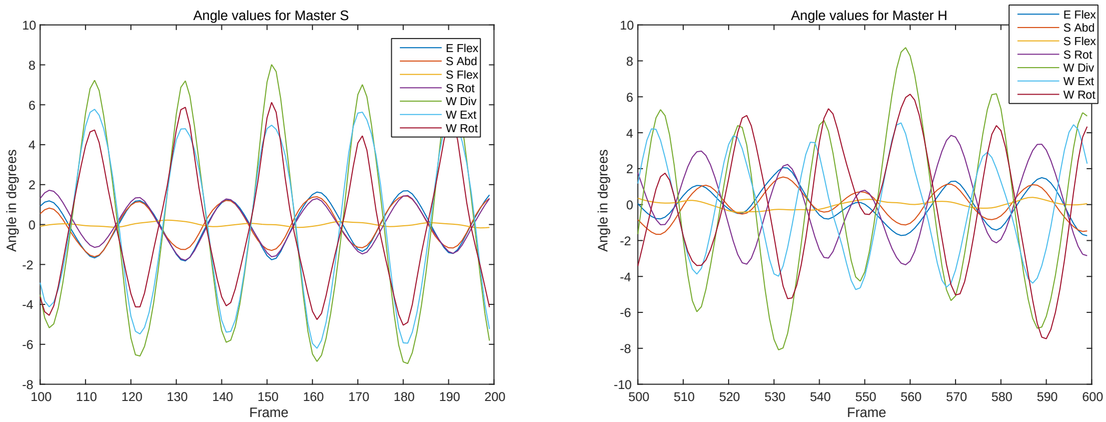
So far we have looked into the position of the RFIN marker in the three dimensional space. The fact that different body parts seem to move little or nothing at all when compared to the right arm lead us to believe the whisking action is defined solely by the movement of the right arm. But marker positions are not the only data that can be obtained with the Plug-In Gait model. The angles in the different joints in the body can also be calculated with it. In this section we will look into three joints in particular: the shoulder, the elbow, and the wrist.

4.3.1 | Phase analysis

The shoulder angle has three degrees of freedom as does the wrist, but the elbow can only be flexed or extended, so it is considered to have only one. This result with seven angles to be analyzed. They are all calculated relative to the plane in which the joint operates, so the position, body shape, or orientation have no impact in the analysis. This means we can directly compare behaviors of the joints between subjects.

Out of the seven angles that we were analyzing, shoulder flexion was identified to have no significant variation in the window of interest. This means that the arm does not travel back and forth, instead remaining at the same height for most of the action. The other six angles, however, present a sinusoidal pattern consistent to the whisking action. With this information, we will discard the shoulder flexion angle since it does not contribute to whisking.

The plots in Fig 4.11 and 4.12 are examples of a 100 frame sample of the time series for all the angles. The lines are moved in the vertical axis in order to compare the behavior between them rather than the individual values. Wrist angles have a bigger amplitude than the angles of the shoulder and the elbow. This is the only characteristic we found that was consistent among all the subjects.



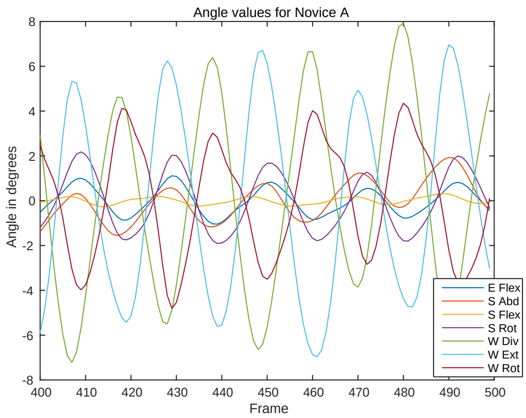
(a) Master S

(b) Master H

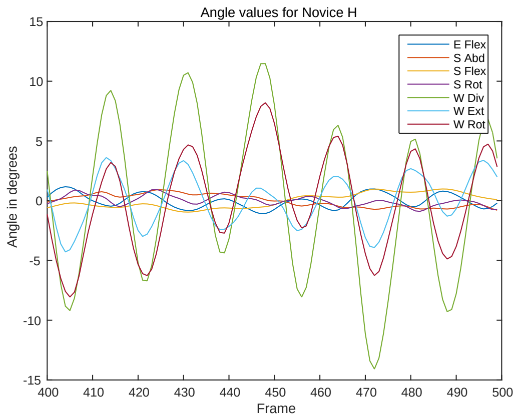
Figure 4.11: Angle time series for Masters

Masters have two different patterns of time series, with them being in antiphase. Master S in Fig 4.11a has the most consistent and stable motion. She has a period about 20 frames and not only the motion has a constant frequency but also a constant amplitude. Wrist angle amplitudes have similar values, as well as the shoulder rotation, abduction, and elbow flexion. Maximums of the wrist group align with minimums of the other three angles, indicating that all the angles have extremes at the same time. All her right arm moves at the same time. Master H, on the other hand, has a less consistent motion that fluctuates more in time. Nevertheless, the same groups can be observed and the alignment of maximums of wrist vs minimums of the shoulder and elbow are present. In Fig 4.11a we observe how the shoulder rotation has a slightly higher peak than the shoulder abduction and the elbow angles, but remains in phase with them.

A difference again can be seen in the Novices, between themselves and with the Masters. Novice H, for example, has a consistent motion in the wrist but lacks any significant movement in his shoulder and elbow as can be seen in Fig 4.12b. This means that he controls the chasen with only his hand and not the whole arm. His wrist extension is also smaller compared to the other subjects, which is reflected in a small area of motion in the RFIN plots in Section 4.1.



(a) Novice A



(b) Novice H

Figure 4.12: Angle time series for Novices

Novice A has a notable difference from the other subjects in that her wrist extension is in a completely different phase compared to the other wrist angles. Fig 4.12a also shows that the wrist rotation is not completely sinusoidal as it appears to have a bump after the main peak that is not present in any of the other angles. However, Novice A does have the shoulder and the elbow coupled together. This group is similar in frequency and amplitude and varies less in time.

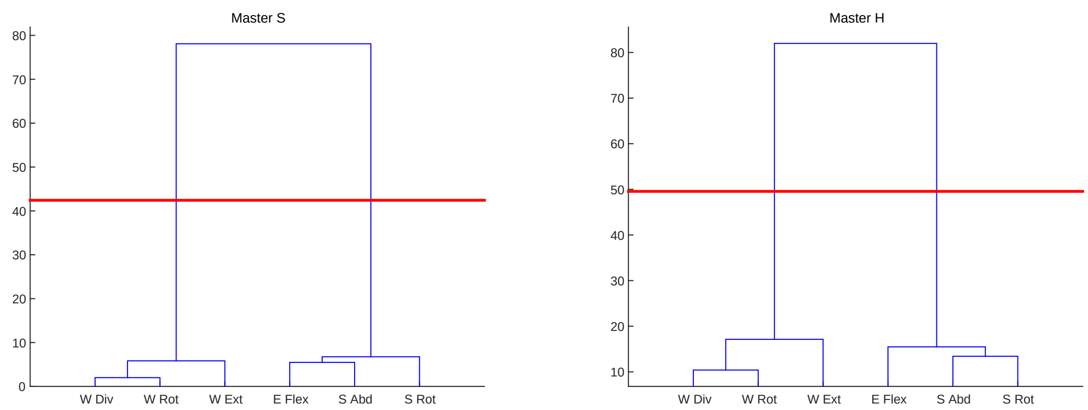
In this analysis we again found that Masters share traits and behaviors, although with different degrees to refinement, and that Novices do not have a defined behavior yet. There appear to be two groups of motion in different, although in antiphase, related to the upper and lower parts of the arm. The coordination and incorporation of the upper arm seems to be relevant to the final result of the whisking. In the next section we will analyze how this coordination holds in a larger time sample.

The rest of the figures for joint angle time series can be found in A.3.1

4.3.2 | Hierarchical Clustering

In this section we analyze the coordination between the different motions in the arm while whisking. For this matter, we selected analyzing the phase of the motion of the angles considered in the last section. For each subject, we selected a sample of 1500 frames and recorded when the peaks of the motion of the seven angles occurred. This data would allow us to show groups of actions that are similar and differentiate them from others at the same time.

For linkage we have used the hierarchical method using the average of the euclidean distances between points. As for the number of clusters, have used a inconsistency coefficient cut off value of 0.9 for the identification of groupings. For representation, we have chosen the dendrograms to show the hierarchical binary cluster and have drawn a horizontal line where the clustering is optimal. All the calculations where conducted with the functions already included in the MATLAB package. The shoulder flexion angle has been discarded as it does not contribute to the motion as demonstrated in the last section, so the analysis was done only on two degrees of freedom for the shoulder, three for the wrist and the elbow flexion.



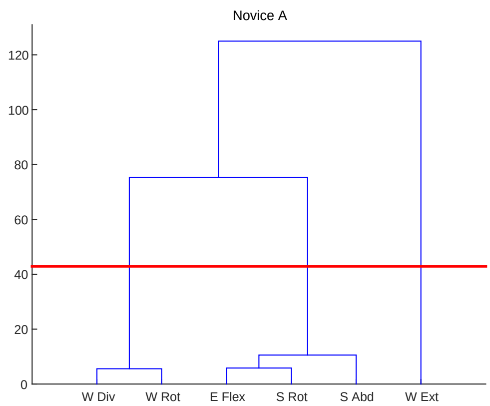
(a) Master S

(b) Master H

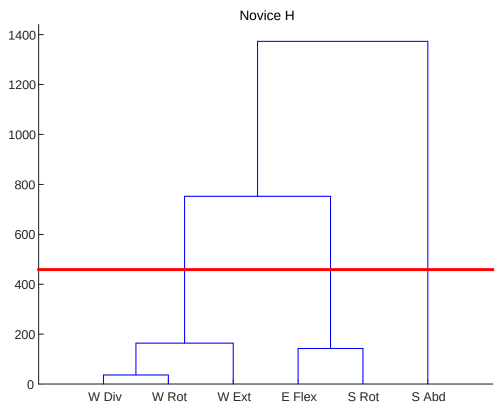
Figure 4.13: Dendrograms for the Hierarchical Clustering of Masters

In Figure 4.13 we see examples of the clustering of the motions of Masters. All Masters and the Intermediate subject present a two cluster configuration with the same members in each group. The wrist angles are more likely to be in phase with each other and the combination of shoulder abduction, rotation, and elbow flexion are in a different phase. The pair of wrist deviation and wrist rotation have the least distance between them compared to other pairs most of the cases. This is in line with our findings in the 100 frame widows previously analyzed. This means the behavior is maintained throughout the whole action of whisking.

Novices, on the other hand, present three clusters and much bigger distances between links. In the case of Novice A (Fig 4.14a) the wrist extension seems to have a different phase and to be uncoordinated with the other angles. Even though it appears in Fig 4.12a that wrist extension has a similar behavior to the upper arm, the linkage shows that it behaves differently in the long run. The window we observed has In the case of Novice H (Fig 4.14b) the uncoordinated angle is the shoulder abduction. Even though there are only three clusters for him, the distances between points are much bigger when compared with the other subjects, thus indicating that the groupings are more stretched than other cases. Novice S has also three clusters, but his groupings are different, as shoulder abduction and wrist extension are coupled together.



(a) Novice A



(b) Novice H

Figure 4.14: Dendrograms for the Hierarchical Clustering of Novices

With the clustering, we have identified that there is a significant difference between the coordination between the actions of the arm of Masters and Novices. The wrist extension and the shoulder abduction seem to be the motions that require more practice to be incorporated to the whisking action and that they are not necessarily incorporated in the same order. On the other hand, practitioners seem to control the rotation and deviation of their wrist since the beginning and form a strong coordination between them.

The rest of the dendrograms can be found in the Appendix A.3.2.

4.4 | Discussion

Masters and Novices have different overall behaviors while whisking tea. Although the action might look similar to the plain eye, the motion capture tool has helped identify the subtle differences. We have been able to identify that only the right arm has an impact on the action of preparing tea. The back has no significant deviation and thus has no contribution to the motion. Even though the head moves, we believe it has no influence to the whisking itself. With this said, we will focus on the right arm.

Since the beginning of our analysis we have identified a path that performers follow to produce tea. This track is an imaginary line that the practitioners develop through time. The Masters have developed the skill to remain in the same space going back and forth in a consistent, stable matter. Although it is not necessarily in the same position for every experienced performer, it is nevertheless identifiable. We also identified that Masters sometimes move outside this track, but consistently return to it. We also believe the more the subject has practiced, the narrower this path gets. The Masters use the whole arm to produce the movement of the whisk in the bowl. When the hand moves to the right, down, and to the inside the elbow extends and the arm moves away from the body and rotates outward. This is especially identified in the actions of Master S, that has a clean, stable motion in the analyzed time frame. Master S and Master M, although with some instability, also behave in this fashion.

Novices on the other hand do not present the track. Novice H and Novice S do not seem to follow a line and ramble around a point and have no back and forth motion. Novice A does present a line, but it does not seem to be the same along the time series. The main difference with her and the Master is that her line drifts and does not converge to a stable position. The Intermediate S presents characteristics similar to both groups. She has not developed a narrow, constant path in which the whisk moves, but has developed the consistency of using her whole arm at the same time as the Masters did. The main difference that the most seasoned practitioners have converge point and she does not.

The subjects can also be divided in two groups by the school they belong to. Novice A has a significantly better performance than the other two novices. We believe that is because she has a higher frequency of practice and also a better example in Master S. Novice H and Novice S have a deficient performance that is not similar to any of the other subjects that suggest that not enough practice in whisking is emphasized in the group. Intermediate S, on the other hand, has a better performance that suggests that not only she has been studying for a longer time, she has practiced more during this time.

Chapter 5

Conclusion

We have been able to prove that subtle, small differences in the movements of practitioners of the Japanese Tea Ceremony are not trivial and thus are enough to characterize the whisking. This characterization showed that the practitioners follow a path that is where the motion converges to. In order to produce the movements over this track, the whole arm is needed. We have demonstrated that coordination is a key element of a good whisking action. By this effect, we have introduced the skills of the Japanese Tea Ceremony practitioners to the light of skill science.

5.1 | Answers to the research questions

In this research, we characterized the action of tea whisking by Japanese Tea Ceremony practitioners. We collected data with a motion capture camera arrangement and analyzed the movements of seven subjects divided in three groups: Masters, Intermediates, and Novices. It has been identified that experienced practitioners have developed a path on which the hand moves most of the time. Their movements converge to that line even when parting from it. The same cannot be said for the most inexperienced performers that have no significant pattern in their motion. With this in mind, we would like to return to discuss the research approach and explain whether the hypotheses were proven or not.

The skill of practitioners tends, over time, to an ideal that is the same for all

Masters have the same characteristics in their actions and we have been able to reach this conclusion through different analysis approaches. The track that the hand follows is the best example of the ideal that we purposed existed. Preparing the tea is the most important part of the ceremony and as such it is tried to be perfected for practitioners that want to study the art for a long time. The knowledge that is passed down from the top management is shared mostly by example and, with the same example for all rankings, the result makes sense. The key in this interpretation of the data is the performance by Intermediate S. With a quarter of the time since starting studying *chado* when compared to Master but considerable more time than the Novices her result follows right in the middle, with characteristics of both groups. This reflects the converge to the ideal and is relevant.

Coordination is the key to a better performance

The right arm was the only part of the body that moved in our observations of whisking. Nevertheless, we were able to identify different patterns of coordination in it. Masters appear to move the whole arm at the same time with better results in the production of tea and creating a stable motion. Novices have not developed the motion of the whole arm together and it impacts the final product significantly. We believe after our research that the whole arm should be used to produce the line to produce the best results.

Students have no discernible mutual patterns

Contrary to all the similarities and characteristics found on the whisking of Masters, the less experienced practitioners have no identifiable shared traits. This was true for students of the same school and of different schools. The subject sample, however, limited our analysis in inter-school comparisons so we cannot make definite conclusions on this particular matter. Practice seems to have more impact in the development than the school where they get their knowledge. This makes sense if we consider that the embedded information in the Masters actions is more or less the same.

5.2 | Limitations and future work

One of the most important limitations in this research is the lack of subjects, especially of intermediate ones. This has undermined our capability to produce a conclusive answer about our third research question. In order to clearly identify the progress from the novice group to the master group, a larger sample has to be analyzed. We also propose recording the final product of tea and make a relationship between motion and visual aspect of tea.

Another area of opportunity is to reach out to practitioners of other houses of chado. In the present research we have only looked to the Urasenke tradition of Tea Ceremony, but different houses might produce different results. As we have identified in this work, differences are small but not trivial and we expect to see differences from house to house as their set of rules and therefore example for tacit knowledge is decided by different people.

The usage of motion capture packages such as the Nexus makes possible to produce videos of only the markers moving in the three dimensional space inside the package. We have been interested in developing artificial data in order to receive unbiased input of whisking and other basic actions by experienced performers to better understand the knowledge acquisition process and the embedded information in their motions.

5.3 | Final thoughts

Tea Ceremony has been so far treated as a form of art, a socio-cultural phenomenon, and even as a religion. Nevertheless, it had not been analyzed for its actions inside the room. For a philosophy that embraces the development of body and mind as one thing, we hope that this research will help feed both the mind and the body knowledge of curious practitioners. That being said, we are more interested with skill scientists taking more interest in other skills that are no so common or obvious. We hope this research helps people get interested, in many ways, in the Way of the Tea.

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Appendix A | Additional Tables and Plots

A.1 | Marker Positions

	Novice A	Novice H	Master H	Master M	Novice S	Master S	Inter S
LFHD	3.675	7.950	1.200	9.327	3.535	1.371	3.961
RFHD	3.487	8.035	1.144	8.905	3.459	1.479	4.253
C7	1.228	3.986	0.870	2.976	0.690	1.030	1.058
T10	0.909	1.929	0.672	1.604	0.462	0.678	0.395
CLAV	1.003	3.045	0.910	2.838	1.047	0.669	1.404
STRN	1.048	1.316	0.403	2.090	1.465	0.470	0.896
RBAK	1.193	3.322	0.886	2.493	0.574	0.826	0.668
LSHO	1.231	3.434	0.730	3.001	1.122	0.868	1.142
LUPA	0.845	2.917	0.530	2.508	0.731	0.726	1.566
LELB	0.269	1.572	0.521	2.041	0.558	0.710	0.742
LFRM	0.392	0.924	0.365	2.108	0.525	0.664	0.512
LWRA	0.344	0.572	0.413	3.022	0.693	0.556	0.411
LWRB	0.160	0.269	0.554	2.787	0.700	0.559	0.949
LFIN	0.234	0.274	0.421	3.306	0.924	0.829	0.679
RSHO	1.210	3.176	1.134	3.672	0.660	1.077	1.680
RUPA	1.506	2.462	2.291	7.025	1.566	0.882	2.185
RELB	2.125	3.073	3.169	10.685	1.830	1.078	3.452
RFRM	1.907	3.846	4.288	12.289	2.153	1.414	4.546
RWRA	1.626	4.229	4.409	12.889	3.092	1.682	5.737
RWRB	3.501	4.543	5.600	12.446	2.605	2.694	5.795
RFIN	6.883	9.190	7.992	17.213	4.747	3.914	10.030

Table A.1: Standard Deviation on the X axis of upper body markers

	Novice A	Novice H	Master H	Master M	Novice S	Master S	Inter S
LFHD	1.470	1.931	1.103	3.882	1.530	0.716	1.920
RFHD	0.670	1.865	1.136	2.967	1.065	0.719	3.280
C7	1.039	1.557	1.009	2.878	0.721	0.314	1.831
T10	0.708	1.204	0.840	1.422	0.680	0.189	0.682
CLAV	0.476	1.089	0.772	1.561	0.656	0.272	0.996
STRN	0.427	1.744	0.558	0.820	0.582	0.341	0.482
RBAK	0.845	1.682	0.686	2.284	0.905	0.526	2.063
LSHO	0.758	1.096	0.755	3.212	0.741	0.278	0.740
LUPA	0.416	0.955	0.421	3.096	0.613	0.344	0.907
LELB	0.385	0.576	0.769	1.968	0.964	0.477	0.722
LFRM	0.311	0.643	0.886	1.501	0.932	0.501	0.721
LWRA	0.309	0.490	0.524	1.141	0.634	0.412	0.512
LWRB	0.254	0.347	0.981	0.850	0.801	0.682	0.655
LFIN	0.236	0.362	1.049	0.917	0.477	0.377	0.587
RSHO	0.903	1.628	1.128	1.932	1.041	0.706	3.036
RUPA	2.179	2.802	3.426	5.081	1.634	1.536	4.989
RELB	2.884	3.878	4.026	7.863	2.059	1.880	6.708
RFRM	2.211	4.553	3.601	6.718	2.375	1.029	5.840
RWRA	4.015	6.506	3.488	10.612	4.806	2.368	4.273
RWRB	3.162	4.557	4.455	7.334	2.682	3.569	5.451
RFIN	7.830	5.708	6.992	12.426	5.899	9.135	4.542

Table A.2: Standard Deviation on the Y axis of upper body markers

	Novice A	Novice H	Master H	Master M	Novice S	Master S	Inter S
LFHD	2.534	2.030	1.525	6.844	2.326	1.328	3.649
RFHD	2.887	1.693	1.671	6.809	2.511	1.109	3.220
C7	0.972	0.515	0.605	1.127	0.774	0.401	0.681
T10	0.376	0.341	0.697	0.724	0.419	0.442	0.350
CLAV	1.741	0.777	1.023	1.952	0.980	0.410	1.007
STRN	1.489	0.713	0.581	1.341	0.657	0.341	0.513
RBAK	0.509	1.421	0.520	1.175	0.602	0.625	0.680
LSHO	0.743	1.138	0.724	0.678	0.822	0.431	0.760
LUPA	0.729	1.264	0.805	0.819	0.482	0.859	0.775
LELB	0.908	0.983	0.685	1.005	0.619	0.807	1.189
LFRM	0.537	0.751	0.700	1.079	0.766	0.643	0.836
LWRA	0.330	0.411	0.289	1.112	1.303	0.398	0.546
LWRB	0.532	0.492	0.828	1.209	1.112	0.745	0.609
LFIN	0.271	0.302	0.920	0.554	0.646	0.383	0.561
RSHO	1.083	2.590	1.057	2.775	1.163	0.847	1.820
RUPA	2.139	2.715	1.979	5.096	1.444	1.697	4.757
RELB	2.416	2.817	2.243	6.038	1.472	1.987	5.395
RFRM	2.186	3.444	2.305	5.326	2.853	1.902	7.305
RWRA	3.495	4.016	3.912	5.602	4.671	3.400	6.878
RWRB	2.204	4.942	3.102	5.024	3.515	2.022	9.397
RFIN	6.644	11.353	8.322	7.457	9.848	9.418	7.516

Table A.3: Standard Deviation on the Z axis of upper body markers

	Weight	Height	Leg Length		Knee Width		Ankle Width		Elbow Width		Wrist Width		Hand Thickness	
	(Kg)		L	R	L	R	L	R	L	R	L	R	L	R
Master H	61	1470	720	720	220	210	190	170	140	150	140	140	120	130
Master M	48	1545	790	780	190	190	170	170	150	140	120	120	130	130
Master S	53	1610	830	830	200	190	160	160	135	145	110	105	105	110
Inter S	41	1570	800	810	209	192	140	140	135	135	105	105	115	120
Novice S	50	1600	800	800	195	200	160	145	160	165	130	125	120	130
Novice H	90	1750	945	955	250	235	165	175	180	1785	130	140	140	140
Novice A	55	1610	800	790	210	205	170	160	155	160	105	110	120	125

Table A.4: Subject data for the Plug-In model in mm

A.1.1 | Transverse plane

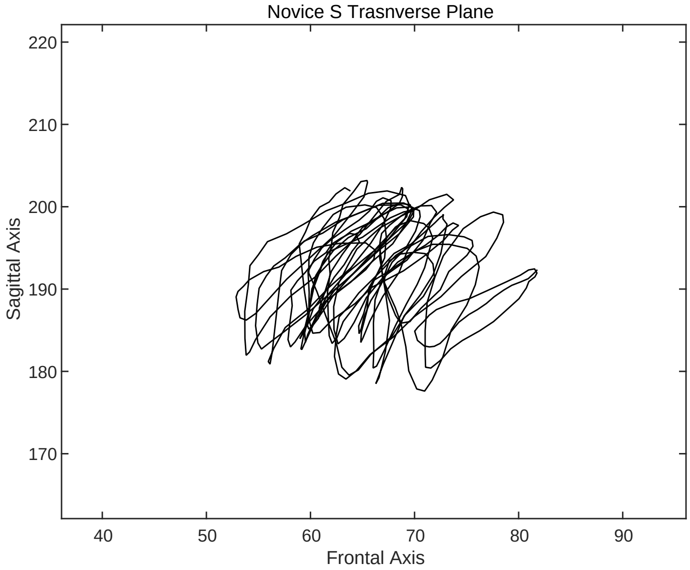


Figure A.1: RFIN positions on the Trasverse Plane of Novice S

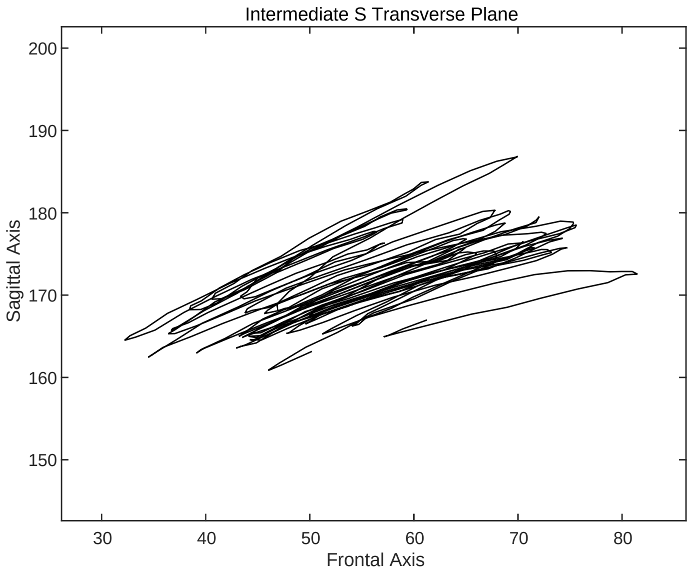


Figure A.2: RFIN positions on the Trasverse Plane of Intermediate S

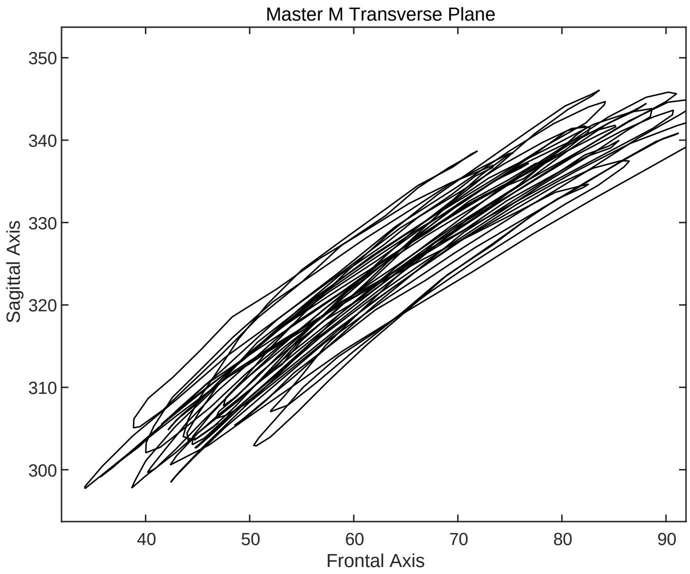


Figure A.3: RFIN positions on the Trasverse Plane of Master M

A.1.2 | Frontal plane

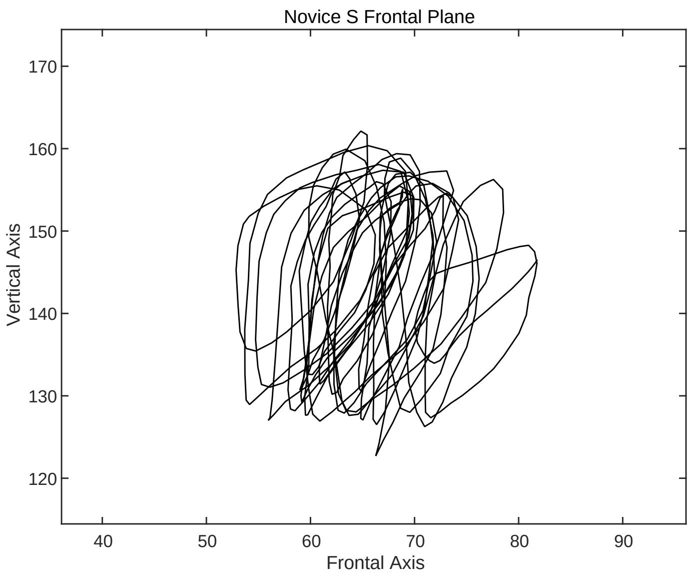


Figure A.4: RFIN positions on the Frontal Plane of Novice S

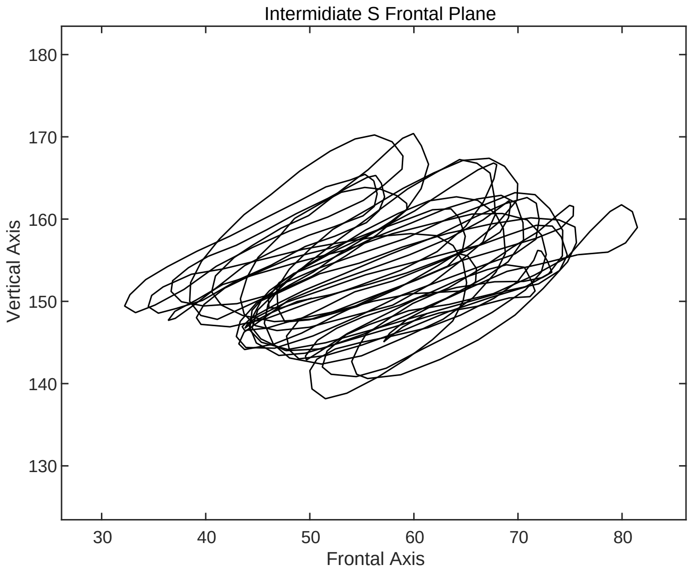


Figure A.5: RFIN positions on the Frontal Plane of Intermediate S

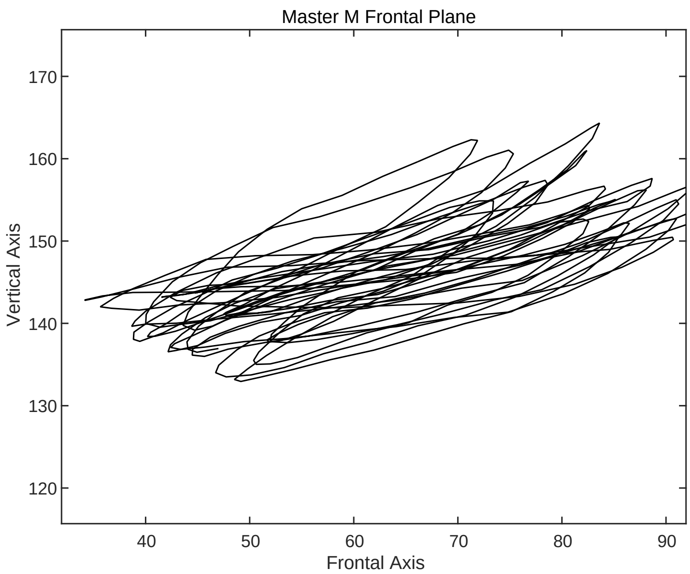


Figure A.6: RFIN positions on the Frontal Plane of Master M

A.1.3 | Sagittal plane

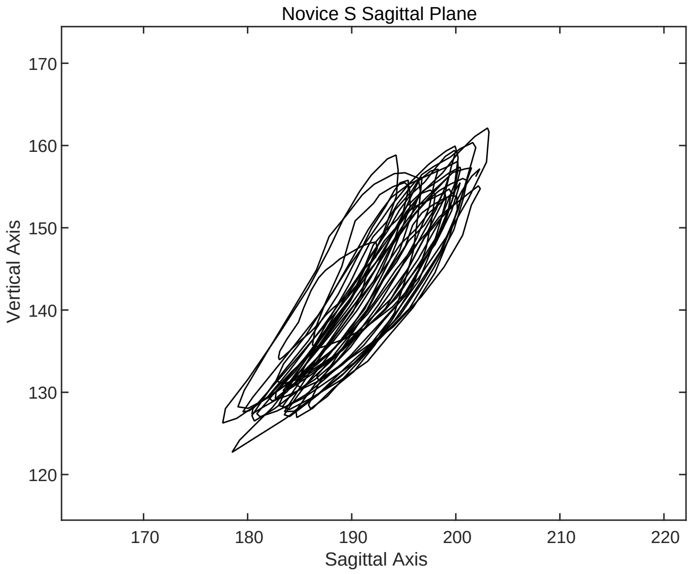


Figure A.7: RFIN positions on the Sagittal Plane of Novice S

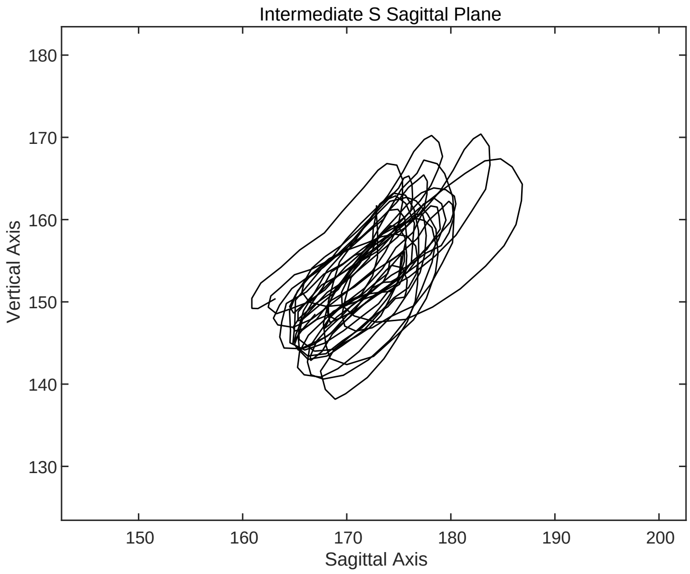


Figure A.8: RFIN positions on the Sagittal Plane of Intermediate S

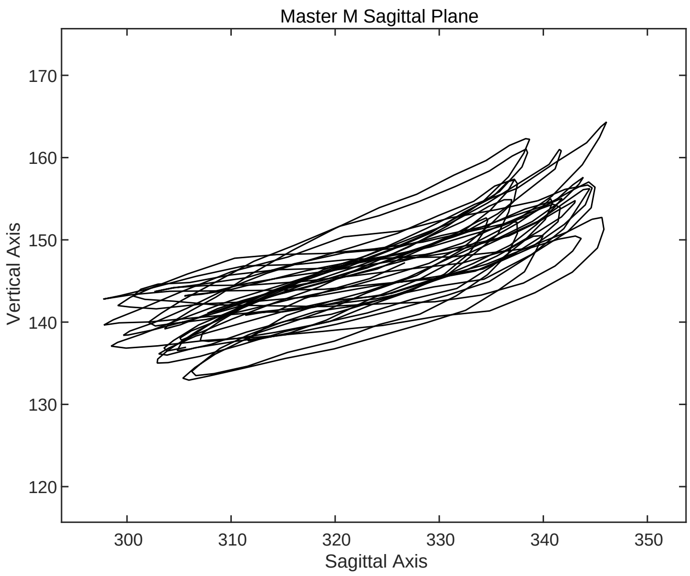
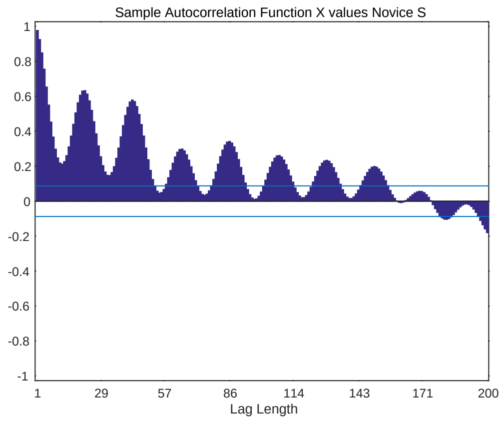
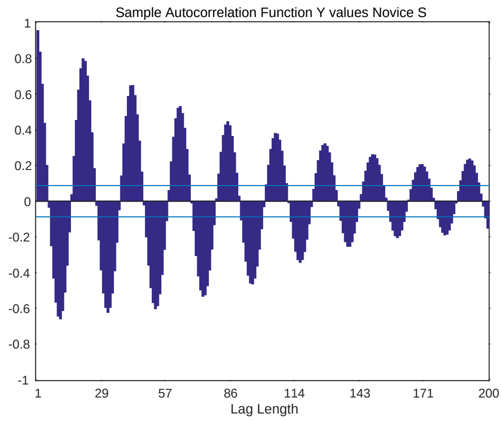


Figure A.9: RFIN positions on the Sagittal Plane of Master M

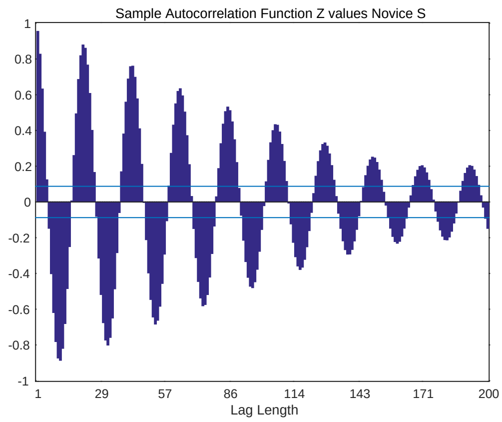
A.2 | Identification of repetition in the action



(a) Frontal Axis

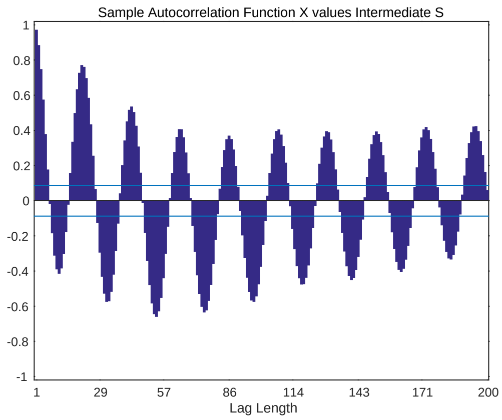


(b) Sagittal Axis

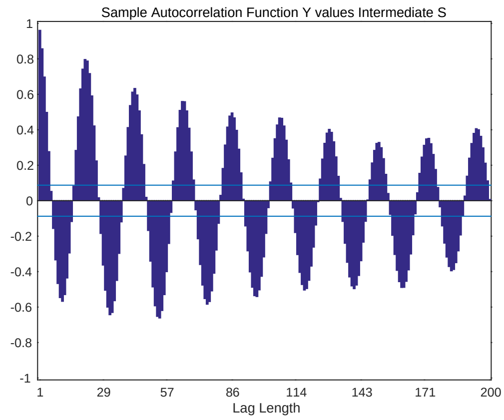


(c) Vertical Axis

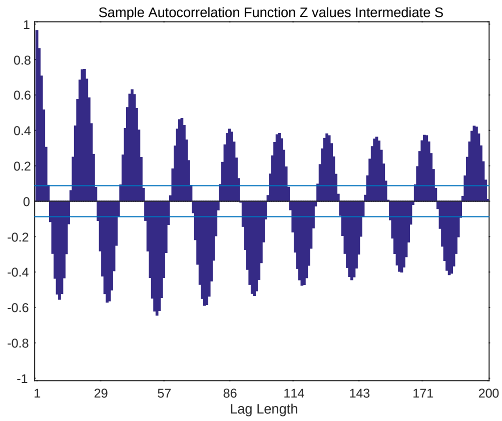
Figure A.10: Sample Autocorrelation Function plot for Novice S



(a) Frontal Axis

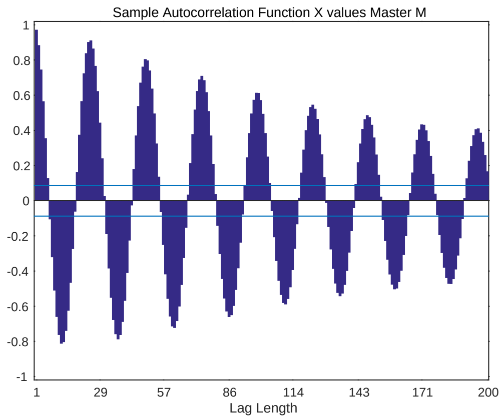


(b) Sagittal Axis

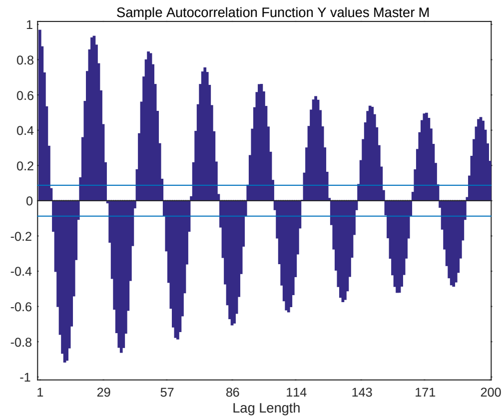


(c) Vertical Axis

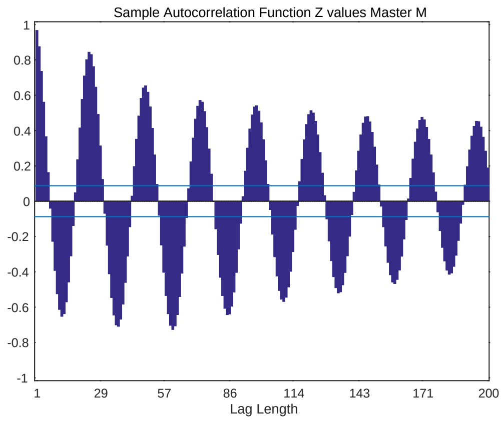
Figure A.11: Sample Autocorrelation Function plot for Intermediate S



(a) Frontal Axis



(b) Sagittal Axis



(c) Vertical Axis

Figure A.12: Sample Autocorrelation Function plot for Master M

A.3 | Joint Angles

A.3.1 | Phase Analysis

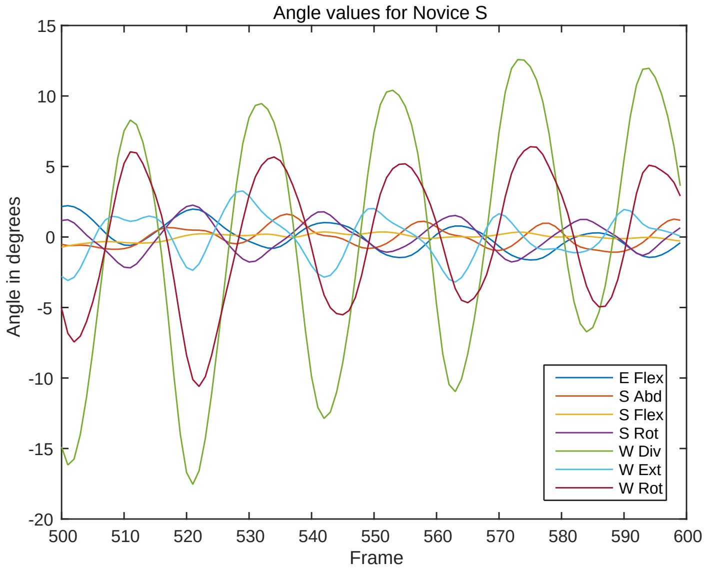


Figure A.13: Joint Angle time series of Novice S

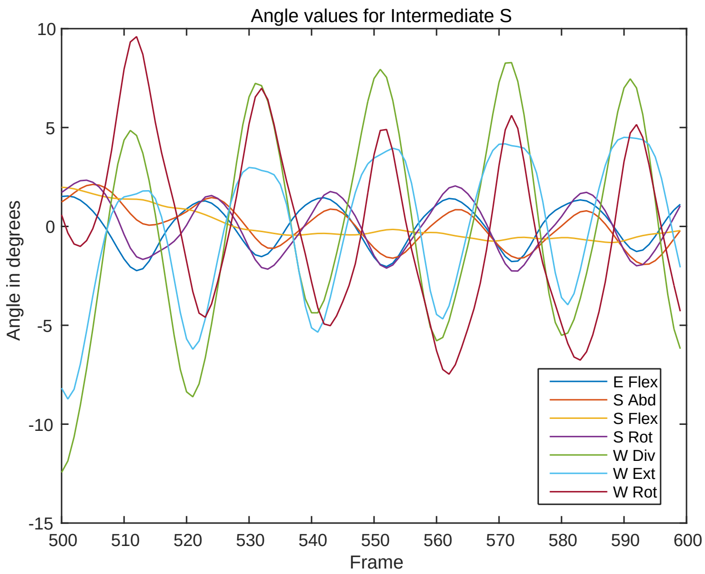


Figure A.14: Joint Angle time series of Intermediate S

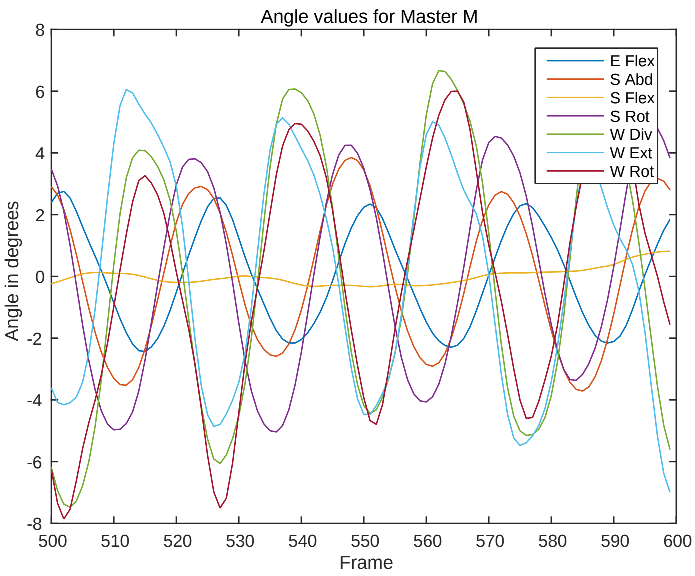


Figure A.15: Joint Angle time series of Master M

A.3.2 | Hierarchical Clustering

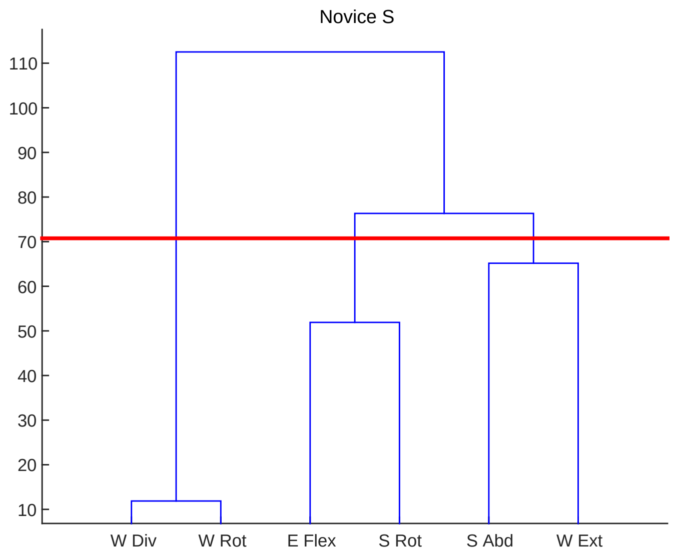


Figure A.16: Dendrogram of linkage between peaks of angles of Novice S

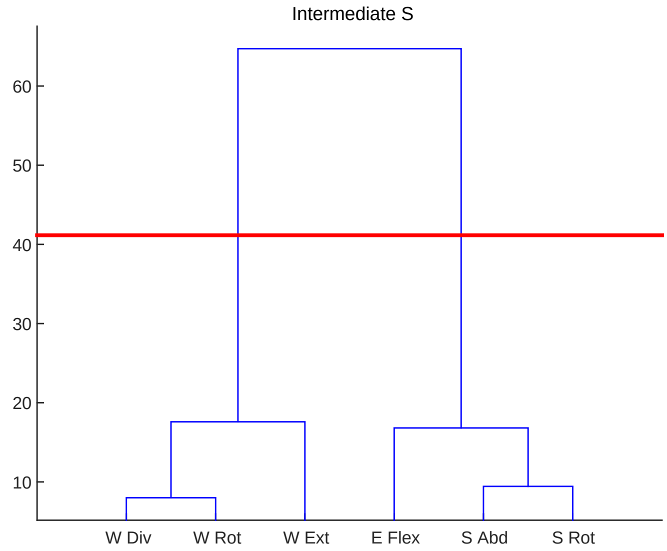


Figure A.17: Dendrogram of linkage between peaks of angles of Intermediate S

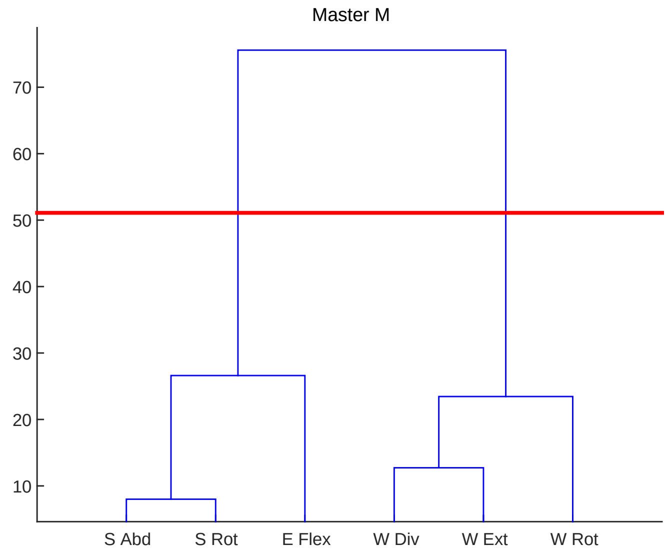


Figure A.18: Dendrogram of linkage between peaks of angles of Master M