The Maestro Myth – Exploring the Impact of Conducting Gestures on the Musician's Body and the Sounding Result

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ABSTRACT

Expert or fraud? Opinions differ widely when it comes to the profession of the conductor. The powerful person in front of an orchestra or a choir attracts both hate and admiration, but which influence do a conductor's actions actually have on the musician's body and the sounding result?
Unlike any other musician, the conductor produces no sound himself, and though the profession of conducting, as we know it today, has existed for more than 150 years, it still lacks a systematic theoretical foundation. Aiming to throw light on the fundamental principles of this special gestural language, this thesis approaches the communication between conductor and musician as a matter of physics and as an analogic – rather than a symbolic – language. By means of two studies we can prove a direct correlation between the gestures and muscle-tension of the conductor and the musicians' reaction in onset-precision as well as the quality and length of the evoked sound. While examining the gestural impact on the sounding result, we also examine, whether and in which way the mere form of the conducting gestures affect the musicians' stress level. With our research we contribute to the development of a theoretical framework on conducting and enable a precise mapping of its gestural parameters, the use of which – not only in the discourse about conducting, but also as a base for hard- and software devices in the education of conductors – could decisively enhance musical learning, performance and expression. Furthermore, this framework provides new insights into a number of aspects of musical perception.

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"You cannot not communicate"

— *Paul Watzlawick*

I INTRODUCTION AND MOTIVATION

1. Motivation

As an active musician I became acquainted with the gestural language of conducting at the age of 13, playing the alto-saxophone in a local youth orchestra. Since then I have played and sung under the direction of many and very different conductors. During college I finally had the opportunity to learn conducting myself. Having to learn the craft then, I wished there had been a clear methodology, as I knew it from other fields. Back then, it was quite disappointing that my professor, a conductor of renown, tried to teach conducting without any scientific explanation, without a teaching book or any visuals, just through telling us to *"feel the music"* and to be *"durchlässig"* (pervious, transmissible) in our gestures. It was only after my exam that I learned about a different conducting method, which clearly explained causality between conducting gesture and sounding result. The experience afterwards to actually be able to convey my musical interpretation in real-time without long explanations, even to my amateur church choir, was game-changing and led me to the decision to explore the underlying mechanisms of this craft scientifically.

2. Introduction

What does a conductor do? Although he is the only musician producing no sounds himself, he is still in the limelight of almost every orchestral and choral performance. The status OF his special role is widely questioned, even within his own "instrument" – the orchestra:

> *"Conducting is surely the most demanding, musically all-embracing, and complex of the various disciplines that constitute the field of music performance. Yet, ironically, it is considered by most people […] to be either an easy-to-acquire skill (musicians) or the result of some magical, unfathomable, inexplicable God-given gifts (audiences)."*[1]

[1] Schuller 1997, p. 3

A conductor leads the orchestra or choir – he decides when to start and stop, and coordinates the tempo and other musical actions in between. Thus, the conductor is responsible for the interpretation, meaning that he decides how to transform the score into sound. These decisions are made within different categories of musical parameters: phrasing (tempo and dynamics), articulation and sound configuration.

But how does he simultaneously show and control this host of rather complex parameters? Even famous conductors such as Alan Gilbert, the Music Director of the New York Philharmonic, are unable to explain what their gestures accomplish:

> *"There is no way to really put your finger on what makes conducting great, even what makes conducting work. Essentially what conducting is about is getting the players to play their best and to be able to use their energy and to access their point of view about the music. There is a connection between the gesture, the physical presence, the aura that a conductor can project, and what the musicians produce."* [2]

But if there is a connection between the conductor's gesture and the musicians' reaction, there must also be mechanisms making this language understandable across instrumental, cultural and language borders.

3. Contribution

For some mysterious reasons, very little fundamental scientific research on conducting exists so far. All attempts to scientifically explore conducting as gestural communication are based on random selections of so-called conducting patterns with no analysis of the physical-mechanical parameters, of which they consist, and by which they must achieve their effect. The same holds true for projects on tracking and mapping of conducting

[2] Roberts 2012

movements. Thus, taking into account the huge variety of different conducting patterns, it is not surprising to find very little consistency in research results.

This research seeks to experimentally prove a direct correlation between the movement quality and form of the conductor’s gestures and his muscle-tension on one side, and the physically measurable reactions of musicians concerning onset-precision, muscle tension, and sound quality on the other side.

Another important aspect of conducting has also been disregarded so far. For many years researchers within the fields of music physiology and musicians' medicine have been exploring health effects of the instrumental and singing practice of professional musicians. Due to this research focus, occupational illness among musicians has mostly been seen as related to factors like overstraining, bad playing technique and posture, general working conditions (no ergonomic chairs, bad lighting, noise exposure, etc.), as well as psychosocial ambience conditions. However, an important factor has been overlooked until now: The impact of conducting-gestures in combination with the accompanying oral instructions on the physical playing actions and stress level of ensemble musicians, which will be addressed in the presented touch-sensor study.

II BACKGROUND AND RELATED WORK

1. Conducting – a Short Historical Overview

The conductor as a leader on the podium in front of choir or orchestra – as we know him today – originated in the first half of the 19th century. However, as a result of a long development, the origins/roots of conducting can be traced back to ancient times. A Roman and Grecian chorus leader stamped his foot to give the beat, and for better audibility he even wore a wooden or metallic clap-sole, the scabellum (see figure 1). [3] Besides this auditive way of literally beating the time, there was an additional practice of musical leadership that is closer to what we identify as conducting: a visual system of hand gestures named *cheironomía* or *cheironomy* [4]. As music notation had not yet been invented at that time, cheironomic gestures were not only used for coordination purposes but also showed the course of the melody as a memory aid for the singers and musicians. First iconographic proofs of these early attempts of conducting as a gestural language can be found in Egypt around the 4. Dynasty (2723–2563 B.C.), but also other high cultures in China and Babylon developed similar cheironomic gestures. [5]

Early Christian music was led by means of gestural hand signs as well and thus formed the basis for the development of music notation (see figure 3 on page 19), the so-called *neumes* (ancient Greek: *neuma* = sign). This early music notation did not indicate precise rhythm or pitch, but showed the general shape of the melody as mirrored in the gestures of the chorus leader.

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[3] Schünemann 1987, p. 3-8

[4] Lind 2012, p. 110

[5] Smits van Waesberghe 1949/1986, Volume 5, 1444

Fig. 1 Scabellum in a fresco from Pompeii. (Sosnovskiy 2008)

Fig. 2 Gregor Reisch: "Typus Musice" (1503). (Galkin 1988)

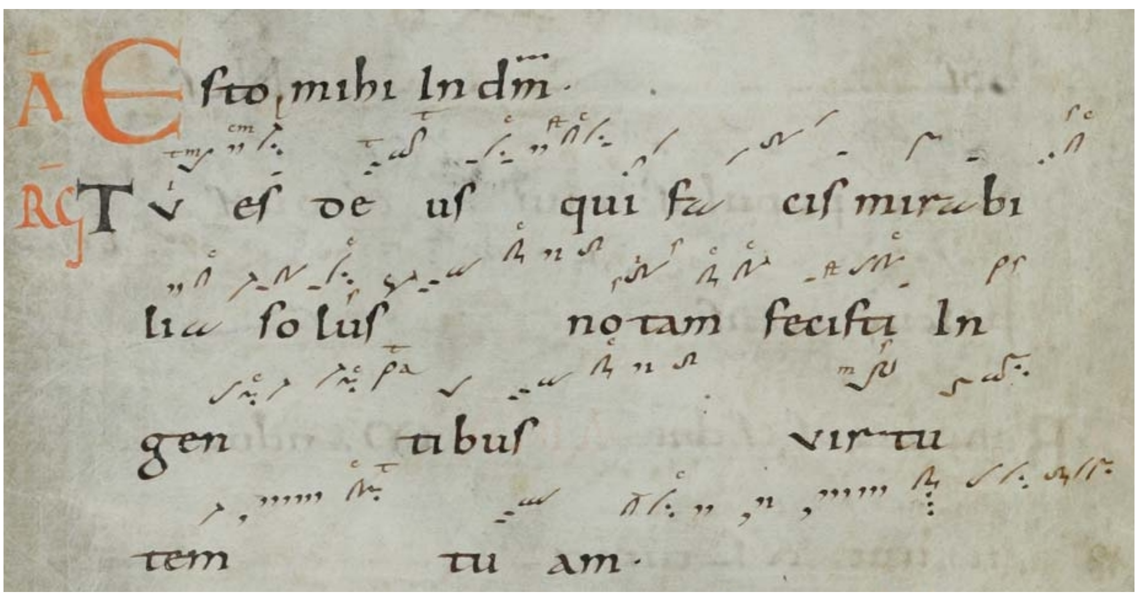

Fig. 3 Codex Sangallensis 359: Graduales Tu es Deus, (after 922 AD)

With the development of the modal notation and the transition from the monodic Gregorian chant to polyphony in the 12th Century, *cheironomy* became obsolete and insufficient, and more advanced types of musical coordination occurred. It was the *cantor's* task to indicate the tempo and to lead the other singers. This was carried out either by beating a long wooden stick on the ground, collective foot tapping, small discrete finger gestures, vertical movements of one hand, or gentle tapping on the neighbor's shoulder.[6]

The early Baroque period sees a distinction between vocal music a cappella and music with the participation of instruments. In vocal music the choral leader still used a stick (see figure 2 on page 19), or waved his hand while holding different objects such as rolled scores or handkerchiefs panned like a flag.[7] In instrumental music the *Kapellmeister* led the orchestra from the cembalo, mostly by supporting harmonically and rhythmically from his instrument, but occasionally also by hand gestures.[8]

The decline of the basso continuo practice during the second half of the 18th century led to a shift of musical leadership from the cembalo player to the first violin player. Most often composers themselves led the performances of their compositions; Bach, Gluck, Haydn and Mozart led either by means of the cembalo/piano or the violin, while the latter became the most beneficial, as violinists at that time played while standing and thus were easily "readable" for the (growing number of) musicians in the orchestra.

While musical performances in the late 18th century were still led from the instrument, a fundamental change can be observed in the beginning 19th century. Due to increasing complexity of orchestral compositions with the beginning romantic era and the growing size of orchestras, a coordination by musicians could not provide the needed precision and sophistication, so new solutions were sought after.

Composer and violin virtuoso Louis Spohr is considered to be one of the first conductors not leading the orchestra with his instrument, but only with a baton. In his autobiography

6 Wöllner 2007, p. 15-16

7 Schünemann 1987, p. 88-92

8 Wöllner 2007, p. 17

Spohr describes the changing role of the conductor and writes about a performance in London in 1820:

> *"It was at that time still the custom there that when symphonies and overtures were performed, the pianist had the score before him, not exactly to conduct from it, but only to read after and to play in with the orchestra at pleasure […]. The real conductor was the first violin, who gave the tempi, and now and then when the orchestra began to falter gave the beat with the bow of his violin. So numerous an orchestra, standing so far apart from each other as that of the Philharmonic, could not possibly go exactly together, and in spite of the excellence of the individual members, the ensemble was much worse than we are accustomed to in Germany. […] I then took my stand with the score at a separate music desk in front of the orchestra, drew my directing baton from my coat pocket and gave the signal to begin. Quite alarmed at such a novel procedure, some of the directors would have protested against it; but when I besought them to grant me at least one trial, they became pacified."*[9]

The rehearsal and the concert became a great success, and so the "novel procedure" established itself very quickly in the leading orchestras, which had long suffered under the lack of precision. An increasing specialization of the profession occurred by the middle of the 19th century, furthered by the emergence of the bourgeois' musical institutions and the increasing number of performances of compositions from past periods. However, specialized conductors were not common and it was still the conducting composers, such as Mendelssohn, Brahms, Berlioz, Liszt or Wagner, who were in the public eye. Not until the end of the 19th century did the profession of the conductor evolve into the independent occupation of nowadays, which can be studied in most music universities.[10]

[9] Spohr 1955, part 2, p. 81
[10] Wöllner 2007, p. 27-29

2. The Maestro Myth & the Role of the Conductor

Opinions differ widely when it comes to the profession of the conductor. The powerful person in front of an orchestra or choir attracts both admiration, envy and even hate. First evidence of scorn and derision at the narcissistic musician without an instrument reaches back to the end of the 19th century. As shown in figures 4 and 5, caricaturists criticize the showboating poses of the conductor or depict a fleeing audience escaping the conductor's deviled actions.

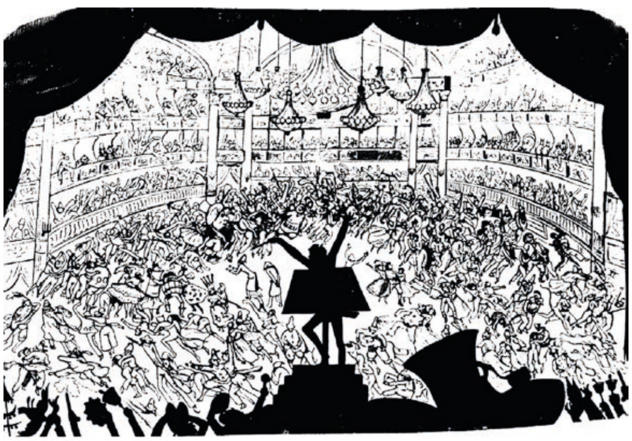

Fig. 4 Gustave Doré: "The Infernal Gallop" (Galkin 1988)

Fig. 5 Bernhard Leitner: Malcolm Sargent (Galkin 1988)

How did it come to such a polarization? Conductors are – as musicians without their own sound – reduced to their body as instrument, requiring precision in use of their gestures, with which they attempt to convey their interpretation of a piece of music to the orchestra or choir, and eventually to the audience. Though these gestures may appear mysterious, exaggerated and sometimes even funny to laypeople, conductors nevertheless are allowed – and supposed – to govern over large ensembles of professionals. Furthermore, the guild of conductors includes personalities with often very special characteristics, proved to be central to the job description of this profession. An introverted musician hardly decides to be the person in the spotlight in front of an orchestra, whereas musicians with a more executive nature, high self-esteem, and a certain predilection for musical-emotional exposure – and the exertion of power – can be found more often on the conductor's podium. As Dieter David Scholz writes in *Mythos Maestro*:

> *„A conductor […] often rules as a dictator. The baton is his scepter. A greater concentration of individuals takes his orders. Thus, conductor and orchestra form a particular miniature image of the social society. The conductor's will and vision becomes sound. He is a leader [...]; sometimes an enchanter, not only of the orchestra but also of the audience."* [11]

This extensively discussed myth surely has its roots within the emerging bourgeois and its private concerts in the 19th century, where art started to be sanctified, becoming the so-called *Kunstreligion*[12] in which the conductor plays the role of High Priest, the central figure of identification for the audience.[13]

In the course of the conductor's professionalization during the 20th century, the *maestro myth* evolved further, additionally abetted by the invention of sound recording media and later by movie and television. Formerly only known by a relatively small audience in concerts, mostly as a composer who led his own music avocationally, the conductor is now at the center of attention in concert-movies and on album covers (see figure 6 and 7 on page 24), and has most recently been seen as the egocentric and impetuous main character in the *Golden Globe* winning TV-Series *"Mozart in the Jungle"*.[14]

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[11] Dieter David Scholz 2002, p. 7 ("Ein Dirigent [...] regiert nicht selten wie ein Diktator. Der Taktstock ist sein Zepter. Seinen Anweisungen gehorcht ein größerer Zusammenschluss von Individuen. Dirigent und Orchester bilden damit ein besonderes Abbild der sozialen Gesellschaft im Kleinen. Des Dirigenten Wille und Vision wird Klang. Er ist ein Anführer [...]; manchmal auch ein Verführer, nicht nur der Orchestermusiker, sondern auch der Zuhörer.")

[12] Brachmann 2003, p. 87; Dahlhaus 2000, p. 573

[13] Alperson 2012, p. 81

[14] Holson 01/15/2016

Fig. 6 Herbert von Karajan: Album Cover (Deutsche Grammophon 1977)

Fig. 7 Herbert von Karajan: Album Cover (Deutsche Grammophon 1969)

Apart from what the myth tells us, what is the actual role of a conductor? Is he an authoritarian sovereign ruling score and ensemble or a communicative democrat? Does the conductor act as the composer's advocate or is he only committed to his own taste?

As discussed in chapter II–1, the conductor's necessity as coordinator of musical performances arose with the increasing complexity of compositions, the growing size of orchestras in the 19th century, and the inclusion of compositions from other eras in concert programs, which also required the conductor's knowledge about performance practice of the different epochs.

These historical functions of a conductor led to a role allocation as follows (see figure 8 on page 25): Beside the conductor himself, also musicians, audience and composer are directly or indirectly involved in the process of conducting. The latter as an artistic creator is located at the outset – he composes a piece of music and publishes score and parts. The musicians practice their single parts usually without knowing the complete score. Only the conductor accesses the full score – he explores the piece through motivic, harmonic and structural analysis, and researches the relevant performance practice, the composer's biography, the genesis and reception history of the piece. This extensive process takes place without public attention, as do the rehearsals with the involved ensembles and soloists, wherein the ensemble, both verbally and gesturally, learns about the conductor's interpretation based on his findings concerning composer and piece. The public performance thus represents the smallest, but at the same time most visible part of the conductor's work.

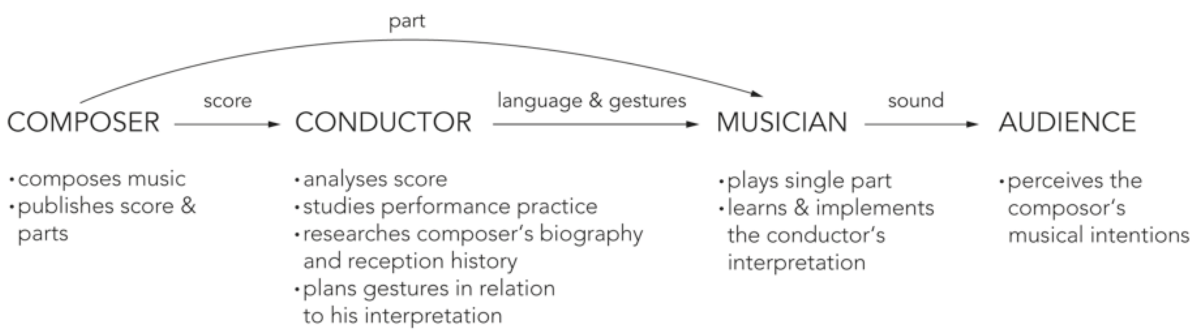

Fig. 8 Allocation of the conductor's role

The audience, being only part of the very last portion of the process, is musically completely at the mercy of the conductor and at the same time cannot not do without him as a figure of identification. Paul Hindemith[15] examined the reasons for the conductor's obvious and crucial importance for the audience; he drew the same conclusion as Canetti[16] and Adorno[17], namely that the audience identifies itself with the conductor's visible exertion of power.[18] Carl Dalhaus even goes one step further in considering the conductor as *"representative of the Kunstreligion"* [19], who became *"speaking subject"* of music, which as a *"speaking art form"* [20] requires a subject for the audience to identify with. As an identification with the composer is not possible due to his absence, and the music itself is

15 Hindemith 1959, p. 171-172

16 Canetti 1980, p. 85-87

17 Adorno 1970, p. 293-294

18 Wöllner 2007, p. 5

19 Dahlhaus 2000, p. 573

20 Dahlhaus 2000, p. 573

too abstract to be tangible, this automatically leads to an identification with the interpreter – with the conductor's gestures as *"visible support"* [21] for the intangible. [22]

In today's concert business, the previously described role allocation is often not practicable anymore. Well-known conductors are travelling from one famous orchestra to the next, having only limited rehearsal time to implement their interpretation. This lack of time for in-depth rehearsals is audible and often leads to character-less interpretations, that are smoothed by compromising about the orchestra's typical sound and playing habits and the visiting conductor's ideas. With little musical originality, the relative importance of the conductor's personality and visual appearance increases in the attempt to attract and entertain the audience. This marketing aspect emerges more or less overtly even in some teaching books on conducting. As Bimberg writes in his famous Handbuch der Chorleitung: *"Every conductor should strive for executing his gestures in the same esthetic quality likewise for musicians and audience".* [23]

Unfortunately, the increasing personality cult of conductors also often influence their self-image as artist. Consequentially, the well-known German conductor Christian Thielemann nourishes myth and contempt alike through saying: *"The worst thing is – you know – that when you put all the attention on the structure, then where is your secret?"*[24]

Thus, the continuing myth seems to build on the conductor's specific character traits that include an unusually high self-esteem promoting the development of a celebrity cult , his obviously important role as a visual mediator between composer, musicians and audience, and a general lack of understanding of the conductor's craft.

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21 Dahlhaus 2000, p. 573

22 Dahlhaus 2000, p. 571-573

23 Bimberg 1989, p. 15

24 Thielemann 2010, 00:32:16 ("Wissen Sie, das Schlimmste ist ja, wenn man nur auf Struktur achten würde, hätte man kein Geheimnis")

3. Related Work

a. Conducting as subject for research and study

Is it at all possible to study the underlying mechanisms of this rather mystifying profession? Surveying the big amount of existing educational programs in conservatories and universities, a whole range of conducting-programs are offered – from basic skills, to Master classes and specialized programs, such as jazz chorus or children's chorus conducting. Beyond that, more than 50 teaching books and a host of smaller compendia on conducting enable self-study on all levels. However, on closer examination doubts arise. There are plenty of detailed and illustrated descriptions of organology, performance practices, vocal technique, rehearsal techniques and musicological analysis, but a systematic conducting method, going beyond very basic gestures, is completely absent. Authors prefer to use vague and indefinable terms, such as aura, charisma or individual expression, and – based merely on their personal experience – describe certain gestures, facial expressions, hand and body postures as being simply 'good or 'not good' (see figures 9 and 10).

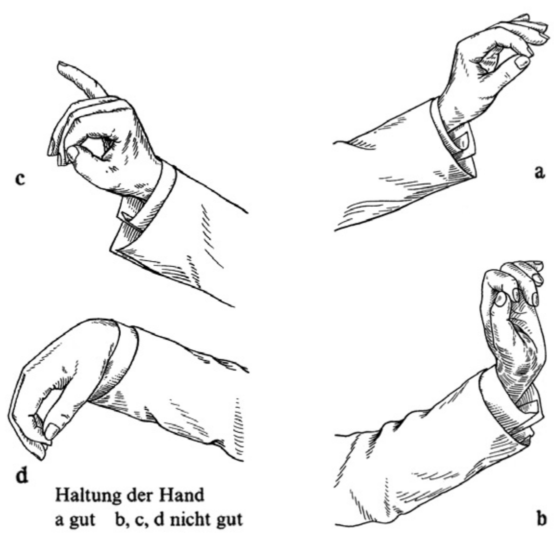


Fig. 9 Hand postures (a "good" ; b, c & d "not good")
(Bimberg 1989)

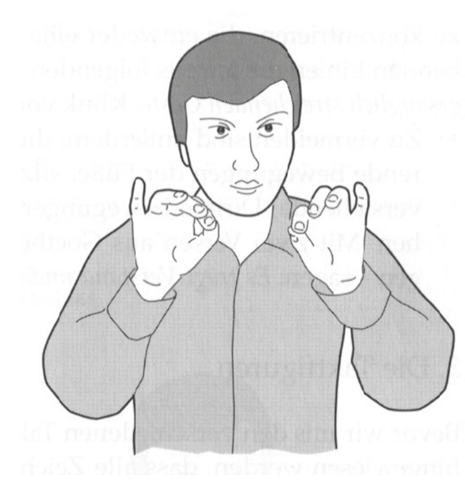
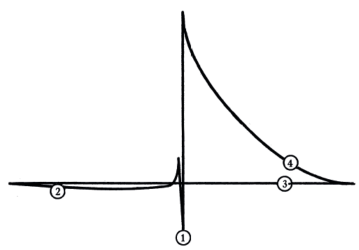


Fig. 10 Correct hand posture
(Bastian 2006)

Furthermore, neither a consistent terminology, nor a generally accepted gestural repertoire, seems to have been established. And although being a visual communication form, teaching books on conducting either completely lack visualizations of conducting gestures or limit themselves to showing so-called beat patterns (see figure 11), which depict the 2-dimensional trajectory of the conducting gesture as seen in frontal view. These patterns even differ widely from teaching book to teaching book (see a more detailed analysis of beat patterns in chapter III).



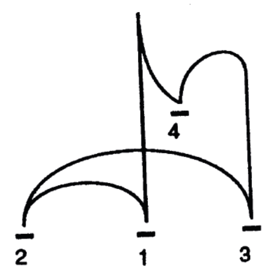


Fig. 11 4-Beat-Patterns from Göstl (left), Rudolf (middle) and Lijnschooten (right) (Göstl 2006, Rudolf 1950, Lijnschooten 1994)

Already in 1929, Herman Scherchen pointed out:

> *"How does one learn to conduct? […] Whenever the problem is discussed with conductors, one finds them underrating it most presumptuously: 'Conducting cannot be learnt; either one is born a conductor or one never becomes one.' Indeed, there does not even exist a standard method of teaching the technique of our art, a method providing teachers and pupils with materials for systematic exercises and dealing, in a gradual order, with the problems of conducting. All books on conducting published so far contain remarks on practical points, polemics on various conceptions of works, and, at best, advice on how to conduct/deal with/address certain works. Some of them give diagrams showing the principal movements used in conducting. But nothing exhaustive is said about how conducting is achieved or how to learn the art of conducting."* [25]

[25] Scherchen 1989, p. 3-5

Although this quote from Hermann Scherchen's Handbook of Conducting dates back to the beginning of conducting pedagogy, a review of modern teaching books shows the same lack of fundamental research and method. Even famous contemporary conductors doubt that their craft is teachable at all. The late Pierre Boulez, for example, stated disenchanted: *"You can only teach how to start and stop"*.[26]

b. Research on Conducting

The main reason for the continuing mystification of the conductor's gestures and personality, and the above mentioned lack of systematic teaching books, seems to be a general absence of fundamental scientific research in this field. Although several other musical disciplines also lack a scientific basis, conducting is an extreme case. So far, only few research projects on conducting have been undertaken. Most research on conducting can be found within the field of musicology, where it primarily explores music-historical topics such as historically informed performance practice or the biographies of famous conductors. And despite the fact, that the tradition reaches back more than 150 years, first attempts of empirical research in this field first appeared the 1980s.

Defining conducting gestures as *"emblems"*, having a direct verbal translation[27], Sousa led a study on musicians' interpretation of conducting gestures . Based on descriptions in five teaching books on conducting, Sousa developed a list of 55 common conducting gestures and their musical meaning, categorized in beat patterns, dynamics, styles, preparations, releases, fermata/holds, tempo changes, and phrasing.[28] A professional conductor with 15 years of experience was asked to conduct all gestures with a consistently neutral facial expression while being videotaped. After an evaluation of the videos by a panel of experts to prove accuracy, the recorded gestures were then shown to 195 members of junior high

[26] Boulez 1994, p. 105

[27] Sousa 1988, p. 8

[28] Sousa 1988, p. 33

school, high school and university bands, who participated by filling in a multiple-choice test, choosing one definition out of four options for each gestural emblem. The results showed a mean recognition of at least 70% for 38 out of 55 gestures, while the overall percentage of recognition increased with age and experience of the participants.[29] These findings led Sousa to the conclusion that the gestural language of conducting is not universally understood, but – like any other type of sign language – has to be learned by the musicians in order to be understood.[30]

Based on Sousa's findings, Mayne[31] explored facial expressions in conjunction with conducting gestures and the effect of conducting-gesture instruction on high-school students. He used 53 gestures form Sousa's study and recorded them again with the same conductor, this time with facial expressions, to investigate the influence of facial expressions on the recognition of conducting emblems.[32] Contrary to Mayne's expectations, there was no significant improvement of recognition with added facial expressions.[33]

The above-mentioned experience-related differences in the recognition-rate of conducting gestures led to Cofer's[34] study, in which he explored whether short-term conducting gesture instructions for seventh-grade band students would lead to better performance in recognizing conducting emblems. His results indicated a significantly improved recognition and performance response after an instructional period of 5 days with 15 minutes of instruction per day.[35]

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[29] Sousa 1988, p. 76-79
[30] Sousa 1988, p. 89
[31] Mayne 1992
[32] Mayne 1992, p. 26-28
[33] Mayne 1992, p. 88-89
[34] Cofer 1998
[35] Cofer 1998, p. 356

A similar approach can be found in an analysis of conducting gestures based on video recordings of Leonard Bernstein and Sergiu Celibidache by Bräm and Boyes; this attempt uses metaphorical associations to compare conducting with sign language.[36] Based on a common orchestral conducting method, wherein the conductor uses his right hand and arm to show beat patterns while communicating parameters of interpretation with the left hand and arm, Bräm and Boyes try to analyze and categorize the gestures of the right hand and arm by means of hand gestures from sign language. According to the authors, similar to sign language of deaf people, metaphorical transference is essential in conducting as well.[37] Bräm and Boyes categorized conducting gestures based on the underlying metaphorical association, such as the manipulation of objects (e.g. grasp, hold, touch), sensing (e.g. smell, hear), visible forms (e.g. drawing lines or surfaces, see figure 12) and co-speech gestures (e.g. Stop!, Go!).[38]

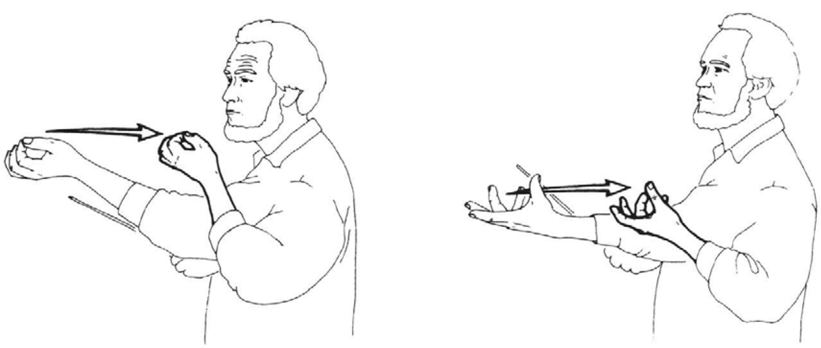

Fig. 12 Gesture of drawing a line (Brähm 1998b)

However, in their attempt to define the desired sounding results of a gesture, Bräm and Boyes allocated different musical parameters to one specific gesture: If a conductor showed a gesture as seen in figure 12, the authors assigned a "slim, light, continuous tone"[39] as sounding result, combining three different categories of musical parameters (timbre, registration and articulation) into one gesture, without further and isolated investigation of

36 Bräm and Boyes 1998

37 Bräm and Boyes 1998, p. 220-223

38 Bräm and Boyes 1998, p. 238

39 Bräm and Boyes 1998, p. 229

each musical parameter. What, for example, if the conductor would like to hear a slim and dense sound? Furthermore, this study only focused on, what a conductor aims to evoke with a specific gesture, and not the actual perception of the musician or the sounding result respectively.

José Serrano's doctoral dissertation from 1993 provides an interesting experimental approach by exploring the predictability of different conducting patterns.[40] Hypothesizing that speed and direction of conducting movements influence the ability to predict a beat, Serrano used constantly blinking points of light representations of conducting movements for his study; he asked forty musicians and forty non-musicians to tap the beat by pressing a mouse button following the point of light animation an a computer screen.[41] The shown conducting movements were categorized in 4 different modes: Mode A (gravity motion), representing motion with naturally occurring gravitational forces, i.e. accelerating when going down and decelerating when going up. Mode B (non-gravity motion), showing the opposite behavior of Mode A, i.e. decelerating downward motion and accelerating upward motion. Mode C (constant speed), presenting the same conducting gestures as in Mode A and B, but with a constant speed. Mode D as mix of tasks from mode A, B and C as means of confirmation of the result of the previous tasks in Mode A-C. [42]

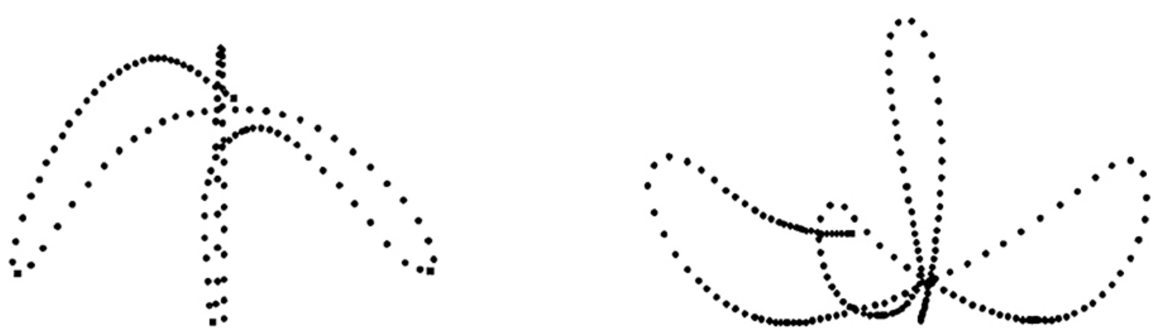

Fig. 13 Mode A (gravity motion) and B (non-gravity motion).
(Serrano 1993)

[40] Serrano 1993

[41] Serrano 1993, p. 35

[42] Serrano 1993, p. 38-41

The results of his study indicate the most precise predictability in mode A (Standard Deviation (STD) 132 ms), in contrast to a significantly higher degree of deviation in mode B (STD 522.8 ms) and mode C (STD 462.3 ms). Although Serrano's results for the different conditions gravity-related tempo changes vs. constant speed seem reasonable at first sight, his experimental design shows a major problem. According to the shown beat patterns of mode A and B (see figure 13 on page 32), Serrano is not only inverting the forces of gravity (the changes of speed can be seen from the different distance between the dots – bigger distance = higher speed), he is also inverting the form of the conducting pattern, thus changing two factors at a time. Without investigating form of trajectory and speed separately, he draws two conclusions: Firstly, the conducting pattern of mode A is easier to predict than the pattern of mode B (see figure 14) and secondly, the gravity mode is beneficial for a precise beat prediction compared to both the non-gravity and the constant-speed mode. Serrano presumes that the main reason for a better predictability of the conducting pattern in mode A is that the trajectory in mode A shows a single, distinct beat point while in mode B "multiple interpretations of the moment of beat"[43] might be possible (see figure 14).

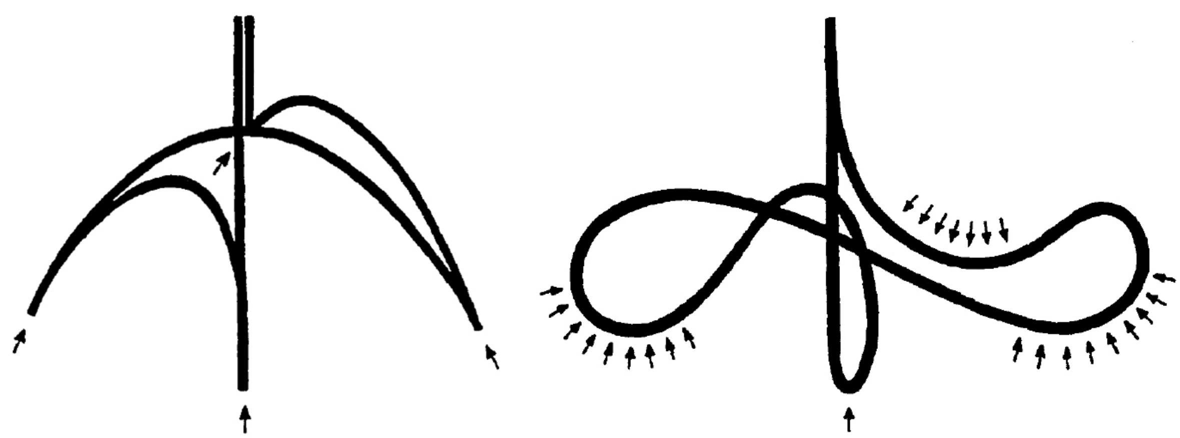

Fig. 14 Predictability of the beat point in Mode A and B

[43] Serrano 1993, p. 45

Teresa Nakra's doctoral dissertation[44] is based on the same orchestral conducting method as in Bräm and Boyes, defining conducting as "symbolically mapped gestures"[45]. Unlike previous approaches, Nakra restrained from analyzing and categorizing the gestures as visual trajectories; instead she developed the so-called "Conductor's Jacket", a custom-made shirt containing sixteen different sensors for measurements of respiration, heart rate, skin conductivity, temperature, electromyogram, and motion. By not comparing the sounding result, but rather using the orchestral score with the data she collected beforehand with four professional conductors during orchestra rehearsals, Nakra aimed to find expressive musical parameters in the physiologically measurable actions of the conductor (See figure 15). Based on this analysis she developed a system, which synthesizes expressive music through a mapping of the sensor-jacket's data-values and transforming them to beat, tempo, dynamics, and articulation of midi-notes.

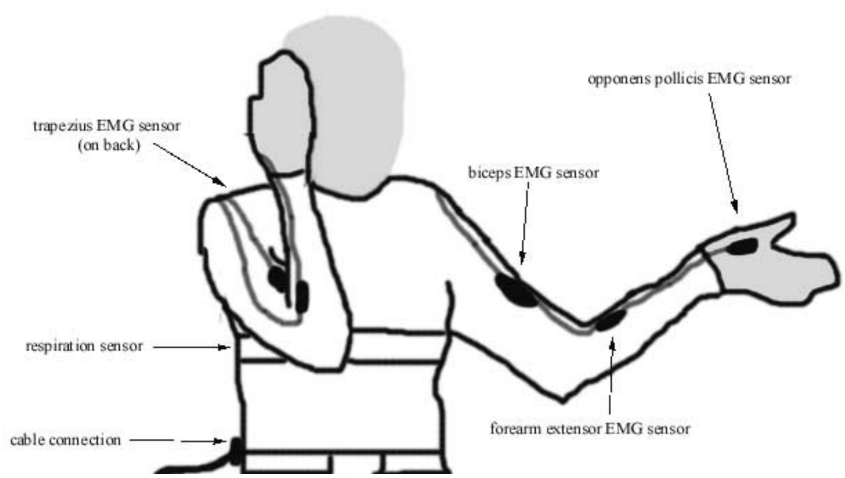

Fig. 15 The "Conductor's Jacket" by Teresa Nakra (Nakra 2002)

An experimental music psychological approach to the perception of expression in conducting gestures is offered by Clemens Wöllner[46]. In his doctoral dissertation, Wöllner investigated the role of different body parts (e.g. arms and face) and different visual

[44] Nakra 1999

[45] Nakra 2002, p. 13

[46] Wöllner 2007

perspectives of the conductor with regard to musical expression. In the first study 36 musically trained participants and 4 experts (experienced conductors) rated videos of five conductors as seen from left-hand, frontal or right-hand view. The highest rating of expressive qualities was found in the frontal view videos, followed by the left-hand perspective. The second study focused on the role of different body parts in conveying musical expressiveness: The frontal view videos from the first study were edited to show either a blurred shape of the whole body to simulate a peripheral vision, a close-up of the face or a close-up of both arms. The results of the second study indicate significantly higher ratings in expressive content for the face close-up video. Based on these findings, Wöllner suggested to integrate an extended training of facial expressivity into conducting teaching methods in order to enhance the repertoire and range of musical expressiveness.

Of particular interest to this thesis are the studies on conductor-musician synchronization by Geoff Luck et al., including different levels of experience of conductors and participants.[47] Luck was one of the first researchers to use an optical motion capture system to explore synchronization between conductor and musicians. In a first study, Luck and Toiviainen recorded a conductor directing an instrumental ensemble in a real-world rehearsal setting and compared the captured gestures with the sounding response of the musicians with regard to synchronicity. A cross-correlation analysis showed that *"the ensemble tended to be synchronized with periods of maximal deceleration along the trajectory of the gestures (medium positive correlation, small lag) and/or periods of high vertical velocity (high positive correlation, larger lag)."*[48] This study identifies features for synchronization of conductor-musician communication and also shows a significant delay between the generally known point of the beat (the lower turning point of the trajectory) and the actual onset of the ensemble.

[47] Luck and Toiviainen 2006, Luck and Sloboda 2006, Luck and Nte 2008

[48] Luck and Toiviainen 2006, p. 196

Based on the previous study, Luck and Nte explored whether different diameters of conducting gestures lead to differences in onset-synchronicity. Using prerecorded point-light representations of single-beats which had been recorded with both an experienced and a novice conductor, participants with different levels of experience were asked to press the spacebar of a computer keyboard while following a life-size point-light representation of single-beat gestures having three different diameters (see figure 16).[49] The results showed no significant difference in onset-precision concerning diameters or between professional and novice conductor, but a significantly higher precision of reactions in the group of participants with experience in conducting.

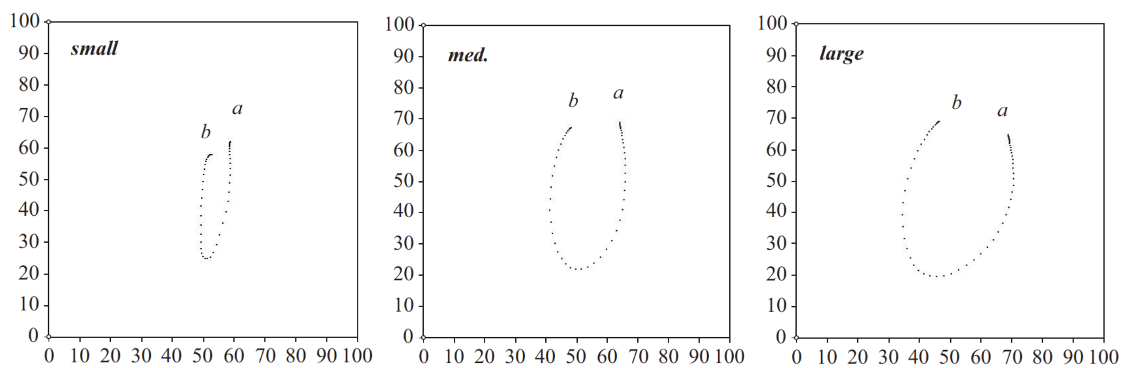

Fig. 16 Plots of the three single-beat gestures produced by the experienced conductor, with the three different radii of curvature (Luck and Nte 2008)

In another study, Luck and Sloboda created point-light representations of 3-beat-patterns, again performed by both a novice and an experienced conductor. Similar to the previous study, conductor-participants, musicians and non-musicians tapped the beat on the spacebar of a keyboard while following the animated gestural trajectories. Consistent with the previous study, conductor-participants achieved the highest level of synchronicity, followed by musicians and non-musicians. In contrast to the earlier study, which did not indicate differences between novice and experienced conductor, a higher synchronization consistency was found in reactions on the novice's gestures. In terms of beat-point location, this study indicated "that musicians tend to be synchronized with features such as high, and

49 Luck and Nte 2008, p. 89-90

frequently negative, acceleration, and low position in the vertical axis"[50], which contradicts the findings of the real-world study. A more detailed review of the studies by Luck et al. can be found in Schuldt-Jensen's analysis, which will be referred to and further analyzed in the following chapter.[51]

The relative effectiveness of verbal instructions and conducting gestures in a high school choral context, as investigated by Jessica Napoles' study in 2014, is particularly relevant for our touch-sensor study (Chapter III).[52] Napoles asked 44 high school students (Grade 9–12) to sing the song "Music Alone Shall Live", while viewing a video with conducting gestures and following different types of tasks regarding word-stress and articulation: (a) Follow the conducting gesture; (b) Contrasting task; (c) Coherent task.[53] The resulting audio recordings were evaluated by 30 experienced secondary choral teachers and then statistically analyzed by Napoles. The results showed a significantly higher quality rating of performances under the condition of verbal instructions with consistent gestures. Interestingly, the sounding results of inconsistent gesture-task combinations were rated higher than those of the gesture-only tasks.[54] Unfortunately, beside a brief description, no further information is given about the exact form/trajectory of the used conducting gestures for the shown musical parameters and the decision process for the selection of the specific beat-patterns.

In a recently published article, conductor and musicologist Morten Schuldt-Jensen offers a detailed description of a conductor's tasks, challenges, and tools.[55] In addition to presenting an overview over the conductor's different communication means and an analysis of the musical parameters, which conducting gestures should evoke, Schuldt-Jensen is the first author to give a detailed analysis of the diverse collection of beat patterns

[50] Luck and Sloboda 2006, p. 42
[51] Schuldt-Jensen 2016
[52] Napoles 2014
[53] Napoles 2014, p. 11
[54] Napoles 2014, p. 13 f.
[55] Schuldt-Jensen 2016

we find in the different teaching books. Furthermore, he gives a detailed analysis of the conducting-studies by Luck et al. and suggests explanations to their seemingly inconsistent arguments. Based on his experience as a conductor and a conducting-teacher, he dismantles gestures to their smallest parts, offering a terminology and a functional explanation of each part of the trajectory (see figure 17) regardless of the conducting style. A more detailed explanation to his analysis can be found in Chapter III as the choice of gesture-archetypes for the presented studies are – among other sources – based on these analyses.

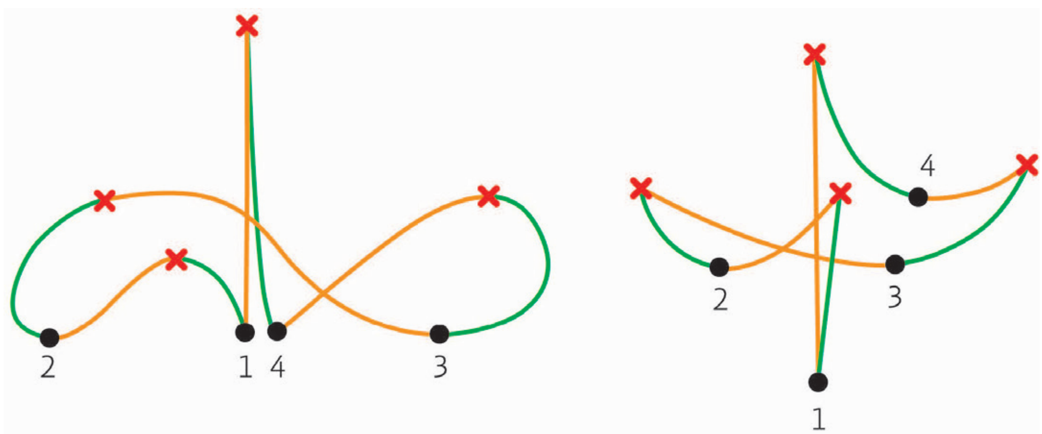

Fig. 17 4-beat-patterns by Göstl and Ericson with a detailed analysis of the 4 sub phases of every beat by Schuldt-Jensen. Pre-beat trajectory = orange line, beat = black dot, post-beat trajectory = green line and turning-point = red x. (Schuldt-Jensen 2016)

b. Research on Multimodal Perception and Expression

The understanding of conducting as an intuitively understandable gestural language is specifically linked to the field of multimodal perception and expression. Of particular interest to the experiments for this thesis is the connection between auditive and visual perception. Findings in experimental psychology show, that we never perceive one sensation isolated, but always in a combination of multiple senses. Michael Haverkamp discriminates different levels of cognitive connections between auditive and visual perception/ imagination and an intuitive or cognitive classification: [56]

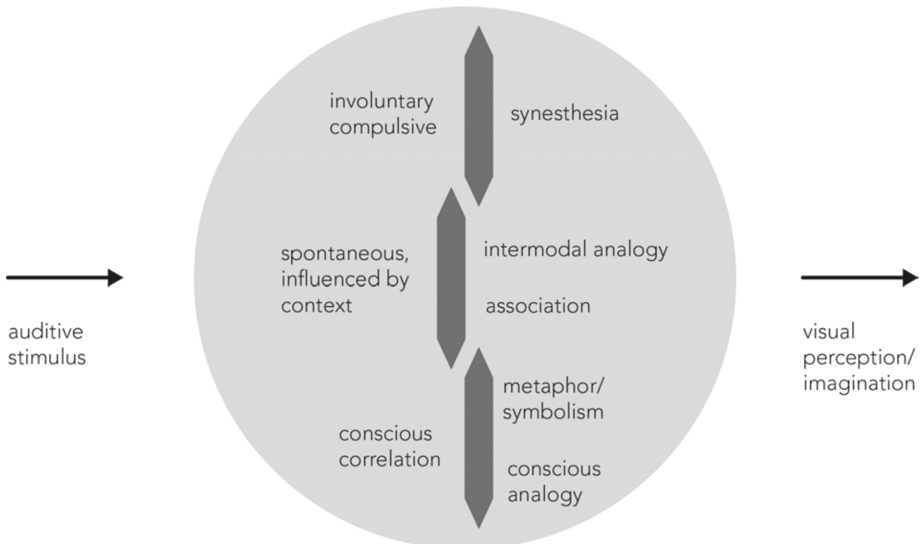

Fig. 18 Connection of auditive and visual perception/imagination based on Haverkamp (Haverkamp)

Whether hearing, seeing, smelling, tasting or feeling, every single sense features specialized sensory abilities, but only the synergetic concurrence equips humans with an essential evolutionary advantage. For instance, following a conversation in a noisy environment is much easier when additionally seeing the movements of the mouth. This integration of sensory stimuli does not only happen through conscious correlation; the crossmodal activation takes place already in early, low level visual areas of the brain through so-called multimodal neurons, sometimes even before object recognition.[57] In case of an impairment of one sense, another sense acts as a corrective; visual orientation in a dark environment – for example – is hardly possible, so auditive perception becomes more dominant for navigation, compensating the lack of visual information. Thus, a robust

[56] Haverkamp, 2001, p. 2

[57] Watkins 2007

perception depends on an efficient combination and integration of information perceived through different modalities. [58]

As opposed to the exceptional phenomenon of genuine synesthesia, all humans are capable of using analogies. In addition to the exclusive qualities of individual senses, such as pitch recognition for the sense of hearing and color for seeing, there are intersensory qualities as well. In the early 1960s, psychologist Heinz Werner conducted first experiments on intermodal analogies, concluding with a list of properties for a characterization of cross-sensory perception, such as intensity, brightness, volume, density and roughness.[59] Similar correlations can be found in Albert Wellek's research, who created the term *"Ursynästhesien"* (primordial synesthesia) to summarize a list of correlations between different modalities, understandable across all cultures and time: [60]

1a	thin – thick	high – low (sound)
1b	sharp (spiky) – (blunt) heavy	high – low (sound)
2	fast, versatile (light) – slow, cumbersome (heavy)	high – low
exception 3a	high – low (in space)	high – low
	up (ascending) – down (descending)	higher – lower
3b	lines horizontal wiggly line	tone sequence duration of sound trill (or tremble)
4a	clear – murky	high – low
4b	lurid (luminous), saturated – pale (grey)	strong – weak
5a	bright (white) – dark (black)	high – low
5b	warm – cold (also color character)	high – low
6	polychrome (colorful) – monochrome (achromatic)	sonorous – monotonous

Fig. 19 Wellek's list of primordial synesthesia correlations (1931). (Wellek)

58 Daurer *(n.d.)*

59 Haverkamp 2001, p. 10

60 Jewanski 1996, p. 98

One example of a cross-culture analogy is an intuitively correct correlation between body height and pitch of the voice, as proven by William Tecumseh Fitsch in 1994.[61]

Another intermodal analogy example is music notation. As mentioned before, music notation originated from hand gestures of the choral leader and showed the general shape of the melody in an analogical manner (see figure 20).

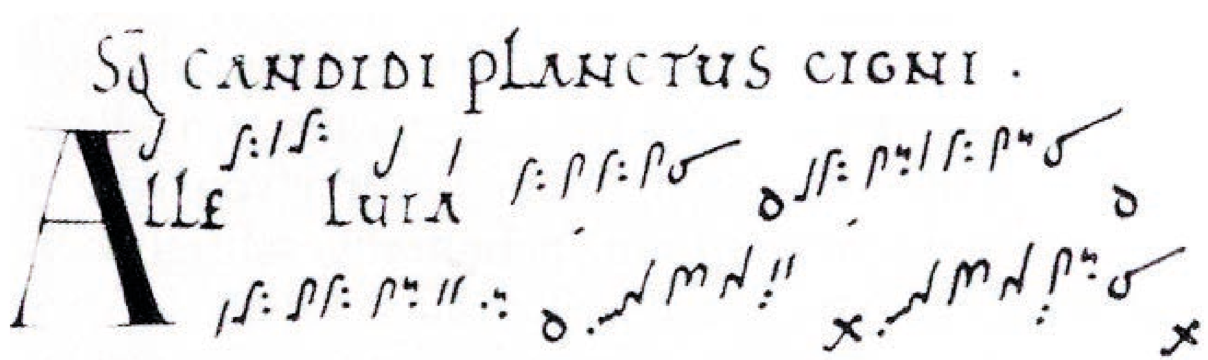

Fig. 20 Winchester Troper, between 1000 and 1050 (Oxford, Bodleian Library)

In special characters of modern music notation, intermodal analogies can still be found, such as symbols for crescendo and decrescendo, staccato and portato or trills (see figure 21).

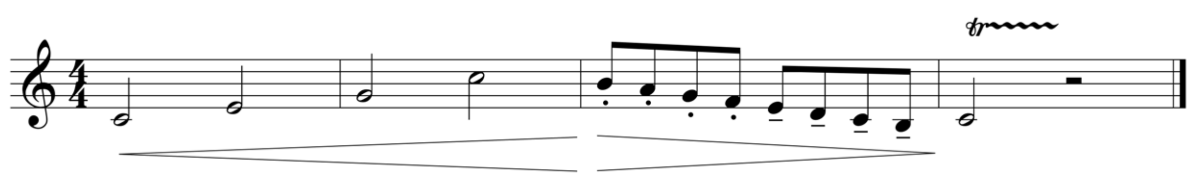

Fig. 21 Expressive markings in modern music notation.

[61] Leßmöllmann 2005, p. 29

In 1929, Wolfgang Köhler – one of the founders of Gestalt Psychology – conducted an experiment in which he explored a non-arbitrary mapping between speech sounds and the visual shape of objects.[62] He showed two forms similar to those in figure 22 and asked participants, which shape was called "Takete" and which was called "Maluma". The result was a strong preference to call the rounded shape "Maluma" and the jagged shape "Takete". Köhler's experiment has been repeatedly confirmed in various settings and variations.[63]

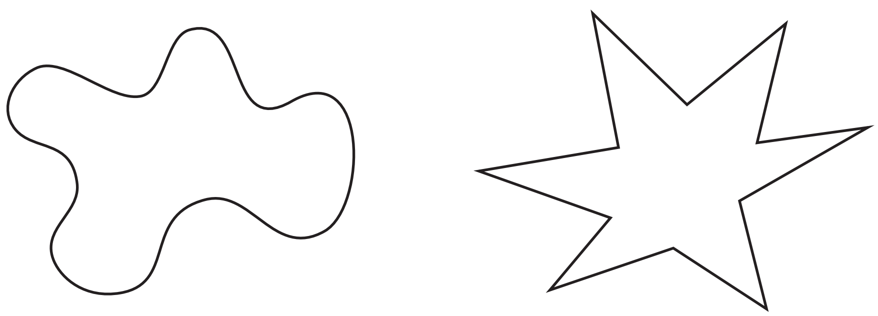

Fig. 22   Maluma (left) and Takete (right)
(Redrawn from Köhler 1929 & 1947)

Two recent studies on the Maluma-Takete-phenomenon are of particular interest in the context of this research. The first study has been lead by Frederico Fontana, exploring an associative correlation of haptic trajectories to the words "Maluma" and "Takete".[64] Fontana programmed a robotic arm to draw a curvilinear and a jagged trajectory. For the experiment, participants were blindfolded and trained to grasp the pen-like handle at the end of the robotic arm to follow the movement of the trajectories. After the short training session, they were asked to memorize both words "Maluma" and "Takete" and assign them to one of the movements, which they were allowed to follow repeatedly until they decided for an allocation. The results confirm Köhler's findings, showing a significant ($p=0.035$)

62 Köhler 1929 & 1947

63 Ramachandran 2001, Maurer 2006, Jankovic 2006, Milan 2013, Nielsen 2013

64 Fontana 2013

percentage of participants associating the jagged trajectory to the word "Takete", proving that cross-modal mapping also holds true for gesture-word combinations.[65]

The second mentionable study by Koppensteiner, Stephan and Jäschke focuses on the correlation between body movements and speech sounds.[66] Based on short videos of politicians giving a speech, the researchers created animated stick figures to be rated by participants. The study consists of two separate experiments:

As for the first experiment, subjects rated subsets of 15 animations by dragging a slider towards one side of a word pair, such as soft–hard, rounded–angular as well as maluma–takete and bouba–kiki. The ratings show strong correlations between the verbal descriptors and the motion measurements, such as velocity and average angle of the animations: High values of velocity and sharper average angles were strongly correlated with the words jerky, hard, fast, takete and kiki, while slow movements with softer angles were mainly rated as soft, rounded, maluma and bouba.[67]

In the second experiment, two contrasting animation clips were presented simultaneously, and the participants were asked to assign each single animation to either being takete or maluma. The results are in line with those of the first experiment and provide strong support for the prediction that slow and round gestures are perceived as maluma/bouba while faster and jagged movements evoke associations with the words takete/kiki.

Another relevant example of research on a similar phenomenon is Manfred Clyne's theory of Sentics. Based on observations of different emotions with their specific dynamic expressions in multiple modalities (such as sighing when being sad or joyful jumping) Clynes hypothesizes the existence of *essentic forms* as innate and cross-cultural form of

[65] Fontana 2013, p. 65

[66] Koppensteiner, Stephan and Jäschke 2016

[67] Koppensteiner et al. 2016, p. 5-8

gestural expression of emotions.[68] In order to determine these expressive movements, he developed the so-called *Sentograph*, a machine that measures finger pressure in both vertical and horizontal direction individually through strain gauge transducers. By means of finger pressure on the Sentograph Clynes conducted several studies in different human cultures to measure the essentic forms of the emotions anger, hate, grief, love, sex, joy and reverence. Figure 23 shows the average of fifty measured essentic forms for each emotion. The upper line represents the vertical component of the finger pressure, while the lower trace displays the horizontal movement.[69]

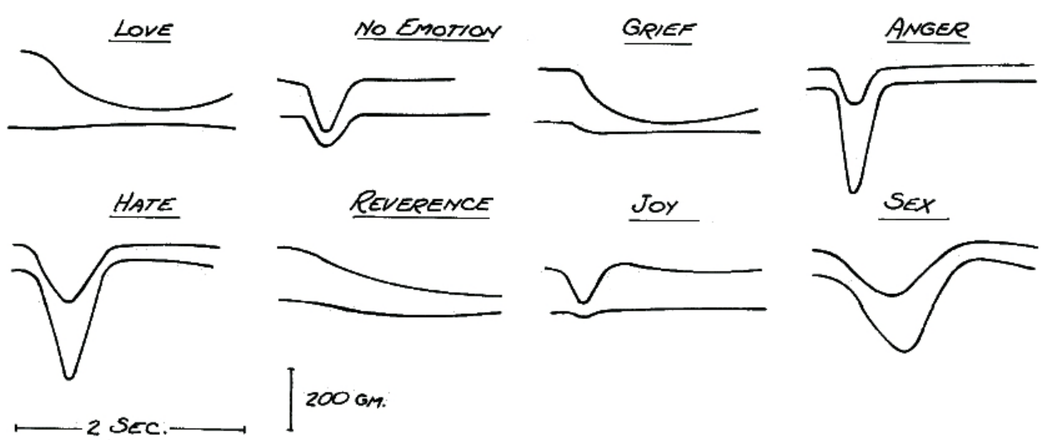

Fig. 23 Manfred Clynes' essentic forms of seven emotions

As is evident from the collected data, Clynes could prove his hypothesis of the essentic forms of emotions to be "universal human characteristics"[70]. Of special interest for the subject of conducting is his claim that "*It is the character of the form, not the particular output modality that determines its emotional meaning.*"[71]

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[68] Clynes 1978

[69] Clynes 1988, p. 113-118

[70] Clynes 1988, p. 118

[71] Clynes 1992, p. 19

c. Research in Related Fields

Beside the above-mentioned research on the gestural language of conducting itself, numerous research projects have tried to capture and map conducting gestures for visualization and sonification or used conducting as a model/inspiration for the creation of expressive electronic musical instruments.

An early motion tracking system in this context was developed by Max Mathews: Based on low-frequency radio transmitters in a baton-like stick and an array of receivers, the so-called *Radio Baton* was the first motion-tracking device to be used for expressive music synthesis and later extended to be used for improvisation as well.[72] In 1997, Teresa Marrin and Joseph Paradiso presented a more advanced conducting-inspired gestural device – *The Digital Baton* – for performing computer music. *The Digital Baton* combines several sensors – including an infrared LED for the retrieval of the baton's horizontal/vertical position, a 3-axis 5G accelerometer array to detect beats and relative orientation of the baton, and piezo-resistive strips for measuring finger and palm pressure.[73]

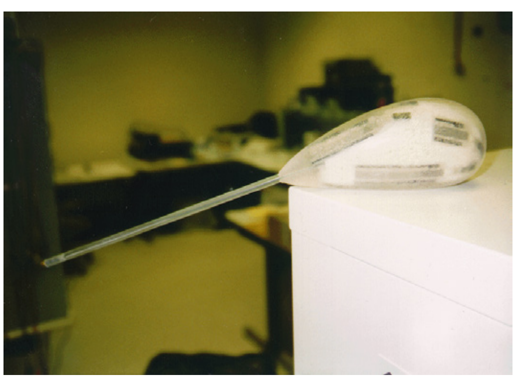

Fig. 24 *The Digital Baton* by Marrin & Paradiso

Fig. 25 Marrin performing with *The Digital Baton*

[72] Lawson and Mathews 1977, Mathews, 1989, Mathews, 1991

[73] Paradiso and Nakra 1997

Alongside further implementations of baton-like devices, such as the *Light Baton* by Bertini and Carosi[74] and the *MIDI Baton* by Keane and Wood[75], other attempts to capture gestural qualities include different kinds of electronic gloves. One of the first devices for enhancing expressive musical performance by hand gestures has been developed by Tod Machover for his composition *Bug-Mudra*. By means of an exoskeletal controlling device, the conductor of the performance was able to precisely control sound mixing and timbre, which used to be impossible in performances with electronic instruments.[76]

Fig. 26 Waisvisz performing *The Hands*

Fig. 27 Laetitia Sonami wearing *The Lady's Glove*

In the 1980s, Michel Waisvisz developed a sophisticated instrument called *The Hands*. The two-part device is attached to both hands and consists of small keys to be played with the fingers, a potentiometer and pressure sensor to be operated by the thumbs, ultrasound transducers to measure the distance between both hands and mercury tilt switches to sense the inclination. This system of sensors allows complex mappings to musical parameters, such as pitch, loudness or timbre and has been used by Waisvisz for many performances around the world.[77] In addition to the above mentioned devices, different forms of sensor-gloves used by performing artists such as Laetitia Sonami and Imogen Heap exist.[78] More

74 Bertini and Carosi 1993

75 Keane and Wood 1991

76 Machover 1992, p. 38-45

77 Bongers 1998, p. 131

78 Sonami 2012, Czyzewski 2011

recently, Elena Jessop Nattinger's doctoral dissertation presents *The Expressive Performance Extension Framework*, a new system for the extension of expressive physical movement by means of a multi-layered computational structure including machine learning to push the boundaries of performance.[79]

In an attempt to map conducting gestures for a live performance, David Nunez and the author designed a system in which a novice, without any musical experience, can perform alongside a professional conductor to create an interpretation of a classical piece of music. Using readily available and inexpensive technology, we can capture and decode both the gestures of experienced and novice participants.

The system consists of two *Leap Motion* controllers capturing the conductor's and the musician's gestures respectively[80]. Compared to other devices such as the *Microsoft Kinect* sensor, the *Leap* sensor has many advantages for our project. Firstly, due to its small size, it is very convenient and easy to use in a stage setting. Secondly, the small, upwards facing capture range is ideal for precise hand and finger tracking. Furthermore, it allows the usage of more than one sensor in a performance setting without any interference (see figure 28 on page 48). The small sensor size and range helps to prevent visual disturbances; on stage, during the performance situation, the conductor, musicians, and audience are likely not to pay special attention to or even be disturbed by the motion tracking technology. Compared to the *Kinect* sensor, which has a frame rate of 30 and a processing time of 100 ms[81], the *leap* controller has a significantly better performance, tracking all 10 fingers with a precision of up to 1/100th of a millimeter at a rate of over 200 frames per second.[82, 83] The *Leap Motion* sensors send x, y and z positions of each hand's joints via

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79 Nattinger 2014

80 Leap Motion Inc. developers page (n.d.), accessed 03/29/2016

81 Štrbac et al. 2014

82 Weichert et al. 2013

83 Leap Motion Inc. product page (n.d.), accessed 03/29/2016

OSC to a processing script. Unfortunately, it is not (yet) possible to connect multiple sensors to one computer. We use two computers with two processing files running, sending the extracted and pre-calculated gestural parameters via a network connection to one *Max/MSP* patch. For larger ensembles, a hierarchical networking configuration might be helpful.

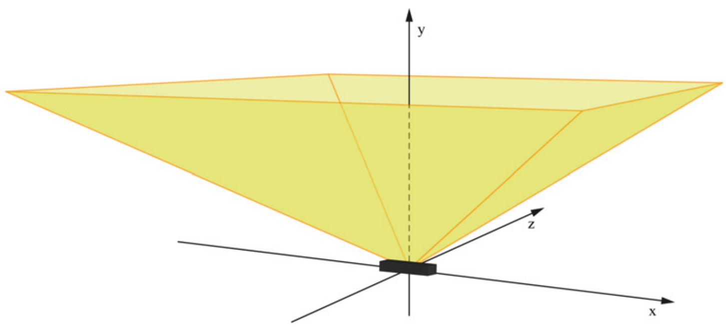

Fig. 28 Capture range of Leap Motion device in xyz-space.

Within *Max/MSP*, the extracted gestural data is mapped to actual musical parameters in order to synthesize a midi-file. The mapping of beat-tracking and volume takes place within *Max/MSP*, while an external Synthesizer (*KONTAKT 5*)[84] modulates articulation, timbre, and vibrato.

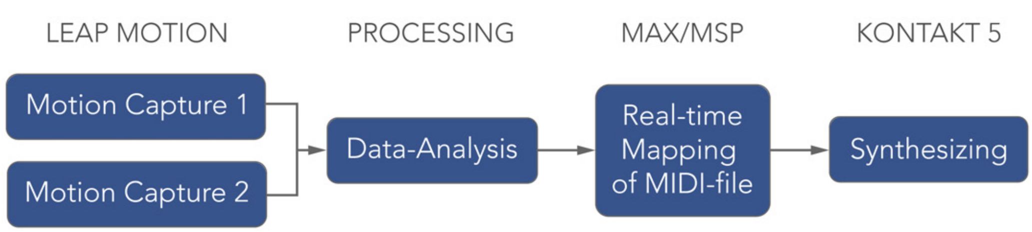

Fig. 29 System diagram showing component technologies and data flow.

In accordance with the primary tasks of a conductor, we mapped the conducting gestures to the musical parameters of tempo, dynamics, and articulation. To support the non-expert

[84] KONTAKT 5 player product page (n.d.), accessed 03/30/2016

musician in creating a musical expression, we use the metaphor of moving hands to *shape* the musical expression in space. The performer could imagine a floating, malleable ball. When casually presented to non-musicians, this explanation appeared to create a joyful, intuitive experience.

As for systems that interpret and synthesize the conductor's movements, Morita and colleagues developed an early example consisting of a combination of two devices to capture conducting movements: First, a baton, held by the conductor's right hand, with a built-in infrared light on it's tip to capture the trajectory and calculate tempo information. A second device – a data glove to be worn on the conductor's left hand – uses optical fiber sensors and a magnetic position sensor to map predefined gestures to musical parameters, such as crescendo, *decrescendo*, *vibrato* and *portamento*, and to detect a pointing-gesture to the virtual position of a specific instrument. Although the technical implementation of Morita's system is sophisticated and well-thought-out, the approach lacks fundamental knowledge of conducting; especially when it comes to beat-pattern classification, the depicted patterns are both inconsistent and partly kinesthetically unrealistic.[85] The same holds true for similar systems developed by Usa and Mochida[86] or Baba et al.[87]

More recent examples make use of depth-sense cameras to track conducting gestures. In 2013, Toh and colleagues presented a system that used the *Microsoft Kinect* as motion capture sensor to map start/stop gestures, tempo, volume, and instrumental emphasis to a synthetic orchestra.[88] Attempting to create a system that is usable by conductors on all levels and without any prior knowledge, the created mappings have a rather high tolerance. For example, tempo tracking is undertaken only on the first and last beat in a bar to avoid

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85 Morita et al. 1991

86 Usa and Mochida 1997

87 Baba et al. 2010

88 Toh et al. 2013

noise and to balance imprecise conducting gestures.[89] This leads to a lack of flexibility in phrasing as the necessary tempo-changes within a phrase usually happen in smaller time frames and not only once every bar.

In two recent studies, Sarasúa and Guaus try to address the problem of the wide variety of different conducting styles by capturing gestures of multiple conductors to find common patterns. Twenty-Five subjects were asked to conduct along with classical music excerpts while focusing on the influence of the dynamics or on the beat of the piece respectively. All participants were recorded with a commercial depth-sense camera and the captured data was analyzed in comparison with the music excerpts. As for the beat-recognition, beats could be partly extracted, but the dynamics recognition analysis did not lead to a general model. Two possible reasons come to mind: First, there is a significant difference between conducting a piece – meaning evoking a reaction – and following an audio recording. Second, according to the paper the participants were somewhat unbalanced in terms of musical background (including subjects without any conducting experience), which additionally could have led to the inconsistent results.[90]

Using beat-patterns from different teaching books or the advice of individual conductors without further review or analysis, the aforementioned projects focus to a greater extent on the technical and mathematical aspects of motion tracking, aiming primarily to map tempo and dynamics. As long as there is no distinct scientific foundation on the effect of conducting movements on the sounding result, such projects will stay highly dependent on individual conducting-styles and a development of general models will not be possible.

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[89] Toh et al. 2013, p.3

[90] Sarasúa and Guaus 2014a, 2014b

III TOUCH-SENSOR STUDY

1. Preliminary Analysis & Study Design

Based on a detailed literature review, we decided to design a study to investigate the following questions within the subject of conducting:

Intuitive Reaction on Conducting Patterns

The literature shows, that there are many abstract multimodal analogies between sound and color, form, size or emotion. Especially the experiments by Köhler[91] prove that there is a non-arbitrary mapping between speech sounds and the visual shape of objects. Köhler's experiments have been repeated in various settings and variations; however, an equivalent consistency in the combination of gestural expressions and sounding reaction in case of a conductor-musician communication, has not been explored yet.
Based on the analysis of Serrano's and Schuldt-Jensen's research, it seems to be of great importance to isolate gestural parameters for unambiguous results. Serrano's experimental investigation showed a high predictability of conducting patterns with parabolic paths (arcs with ends down) and a lower predictability of inverse parabolic paths (arcs with ends up) (see figure 30).[92]

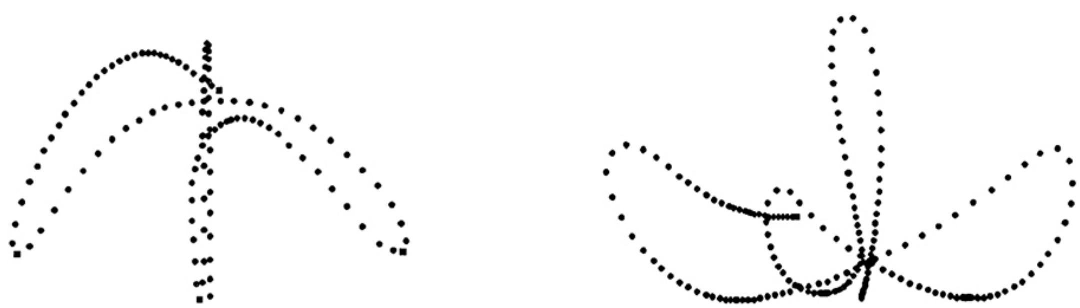

Fig. 30 Serrano's parabolic (left) and inverse parabolic conducting pattern (right)

[91] Köhler 1929 & 1947, see p. 42
[92] Serrano 1993, p. 38-39

Schuldt-Jensen's analysis indicates the exact opposite: he differentiates between four categories of characteristics of the different conducting patterns:*"1) levels of the beating point 2) form of the trajectories 3) form of upper and 4) form of lower vertical turning point"* [93]. Based on this analysis of general beat patterns, Schuldt-Jensen proposes the exact opposite to Serrano, attributing a high predictability to convex trajectories and a lower predictability to concave conducting patterns (see figure 31).

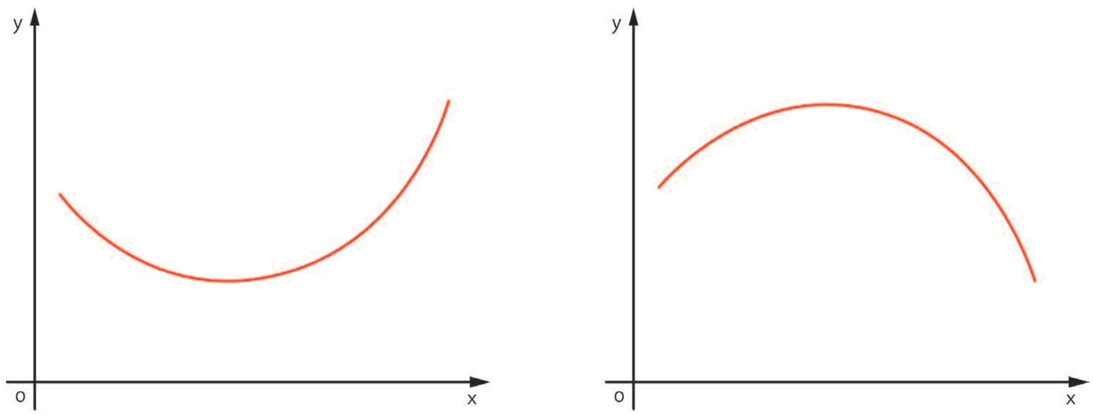

Fig. 31 Convex (left) and concave (right) trajectories according to Schuldt-Jensen

Furthermore, Schuldt-Jensen hypothesizes an intuitively evoked quasi staccato reaction in case of purely concave conducting gestures, and a quasi legato as reaction to convex trajectories.[94] A similar assumption can also be found in several teaching books on conducting, assigning gestures with sharp, jagged beating points to staccato and smooth, rounded ones to legato.[95] In addition, a majority of teaching books also suggest to modify the size of the conducting gesture to evoke different dynamics, using big gestures for forte and small gestures for piano.[96]

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93 Schuldt-Jensen 2016, p. 405

94 Schuldt-Jensen 2016, p. 410-411

95 Green 1992, Farberman 1997, McElheran 2004, Bowen 2005, Hinton 2008, Meier 2009, et al.

96 Hinton 2008, Schuldt-Jensen 2008

In order to isolate the visual information of a conducting gesture as best as possible, we decided to use only the conductor's right hand, and not the left hand which is in some conducting schools assigned to exclusively show the *expressive content* of the conveyed information.

Based on these preliminary considerations, we made the decision to use three different archetypes of conducting patterns for our experiment: Concave, Convex and Mixed (see figure 32). Concave and convex gestures are simplified versions of those used by Serrano, reduced to the pure shape as being convex or concave as defined by Schuldt-Jensen. The mixed gesture is an often taught combination of a concave and a convex trajectory, for example seen in Phillips, Lumley, Thomas and Göstl.[97]

Fig. 32 Concave (left), convex (middle) and mixed (right) archetypal conducting patterns

In addition to the three basic patterns, we are also using a big and a small version of the convex pattern to investigate possible differences in volume of the evoked reaction. The question of predictability becomes especially interesting when it comes to tempo changes. Therefore, as a supplement to measuring the reaction on the three different conducting patterns in constant tempo, we included versions with changing tempo for all three gestural archetypes to see whether response time differs.

97 Phillips 1997, Lumley 1989, Thomas 1992, Göstl 2006

Impact of conducting on the musician's body

Another important issue will be investigated in this study: For many years researchers within the fields of Music Physiology and Musicians' Medicine have been exploring health effects of the instrumental and singing practice of professional musicians.[98] Due to the research focus, occupational illness among musicians is mostly seen as related to factors like overstraining, poor playing technique and bad posture, general working conditions (no ergonomic chairs, insufficient light, noise exposure etc.), and psychosocial ambience conditions.[99] However, an important factor has been disregarded so far: the impact of conducting-gestures and the accompanying verbal instructions – and the combination of them – on the physical playing actions and stress level of ensemble musicians.

Beside the mere gestures, verbal instructions constitute a major part of the rehearsal procedure. We hypothesize, that a (felt) discrepancy between verbal instruction and shown gesture would evoke negative stress, which – over the long term – could result in stress-related occupational illnesses. In order to provide options of future research, we not only ask participants for their intuitive reaction on the previously presented conducting patterns; with regard to possible stress reactions, we also gave contrasting verbal tasks accompanying the shown gestures and comparing potential differences in stress levels of participants.

In view of Jessica Napoles' findings on the effectiveness of verbal instructions and conducting gestures respectively, a comparison of the impact of different pairings of conducting gestures and verbal instructions on length and volume of the elicited tone would also be interesting.[100]

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98 Stanhope 2015, Dommerholt 2009/2010a/2010b, Spahn et al. 2011, Lee et al. 2013

99 Richter et al. 2011, Regenspurger and Seidel 2015, Gembris and Heye 2012

100 Napoles 2014 (see chapter 3b, p. 37 of this thesis)

2. Data Collection

The presented study was approved by the *Committee on the Use of Humans as Experimental Subjects* (COUHES) at the *Massachusetts Institute of Technology*.
Before taking part in the study, all subjects were informed of purpose and procedure of the experiment and informed consent was obtained.

Recording the Conductor

Previous to the main part of the study, we needed to record the different conducting movements as described above. We asked a professional conductor with more than 30 years of experience in conducting a wide range of both professional and semi-professional orchestras and choirs to come to the MIT Media Lab for the video recordings. First, two *MYO* armbands were placed on the right lower and upper arm to record the muscle-tension of the conducting movements. Thalmic Labs' *MYO* armband is a consumer device for gesture recognition, designed to navigate through slideshows or other applications using gesture controls, such as tapping fingers together or opening and closing the fist (see figures 33 and 34). The sensor armband contains eight Medical Grade Stainless Steel EMG sensors, a three-axis gyroscope, a three-axis accelerometer and a three-axis magnetometer, sending data wireless through *Bluetooth*.[101] For our study, only EMG and acceleration data was used.

Fig. 33 MYO armband with numbered EMG-sensors

Fig. 34 MYO armband placed on forearm

[101] Myo Gesture Control Armband (n.d.), accessed 03/14/2016

Using the application *MyOSC*[102] we forwarded raw data received from the *MYO* armbands via Open Sound Control (OSC) messages to *Max/MSP*[103], where we time stamped and synchronized all data (see figure 35).

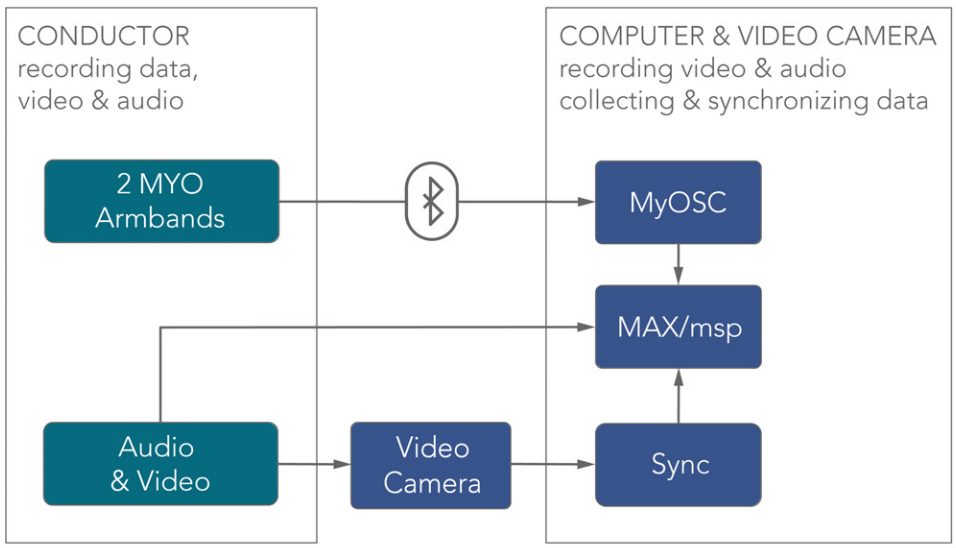

Fig. 35 Diagram of the conductor's data collection

We used a metronome to ensure the same medium tempo (♩ = 68) for all single tasks; for those with tempo changes we used the metronome just for the beginning of each task. The metronome beat also served as reference for defining the conductor's anticipated beat points. In all three archetypes of conducting patterns, beat points are located at the lower turning point of each movement, which matched with the timing of each metronome beat (see figure 36).

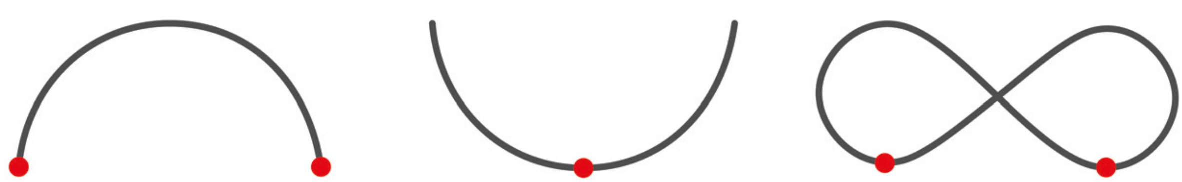

Fig. 36 Beat points for all three conducting patterns

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[102] Kuperberg 2016, accessed 3/16/2016

[103] Cycling '74 – Max/MSP product page (n.d.), accessed 3/16/2016

Recording the participants

Our experiment took place in the *Bartos Theatre*, a lecture hall with a seating capacity of 190. We decided to use this particular room for the creation of a performance-like atmosphere without external sources of noise to animate the participant to perform the test with a high level of concentration. The experimental setup consisted of a screen, showing videos of conducting gestures, headphones for audio feedback and a touch-sensor detecting physical pressure. The touch-sensor was custom-built, using a single zone *Force Sensing Resistor* (FSR) with an accuracy (force repeatability) of +-2% and a force sensitivity range of ~0.2N – 20N, measuring touch events in Millivolt (see figure 37).[104] The collected data was sent though an *Arduino UNO* via serial communication to *Max/MSP*, where it was time stamped and saved into a csv-file.

Fig. 37 Touch sensor

Fig. 38 FlexComp Infiniti Decoder

In order to measure current stress-levels the subjects were asked to wear two electrodes to record electro-dermal activity (EDA) and an optical sensor for blood volume pulse (BVP) measurement on the fingertips of the non-dominant hand. Additionally, a chest belt was used to record respiration frequency and depth. All sensors were connected to a *FlexComp Infiniti Decoder* (see figure 38), which sampled the received signals at 2048 samples/ second, digitized, encoded, and transmitted the sampled data via the computer's USB port

[104] FSR 400 Series Data Sheet (n.d.), accessed 3/15/2016

to the BioGraph Infiniti Developer Tools.[105] The software was used to merge and timestamp the received data, as well as to create one single file per task to be saved as csv-file. Max/MSP was used to start the conducting videos synchronized with the data-collection from the touch sensor and to time stamp and ultimately save the collected data. As the internal video player within Max/MSP did not provide a stable frame rate, we decided to use a Java script to open the video files in an external video player. Unfortunately, this procedure caused a delay between the triggering of each video file and the actual start of the playback. We were able to solve this synchronization problem by embedding a quiet and very low pitch sound (50Hz) at the very beginning of each video to be sensed by Max/MSP and would then trigger the start of the touch sensor data collection synchronized with the actual beginning of the video.

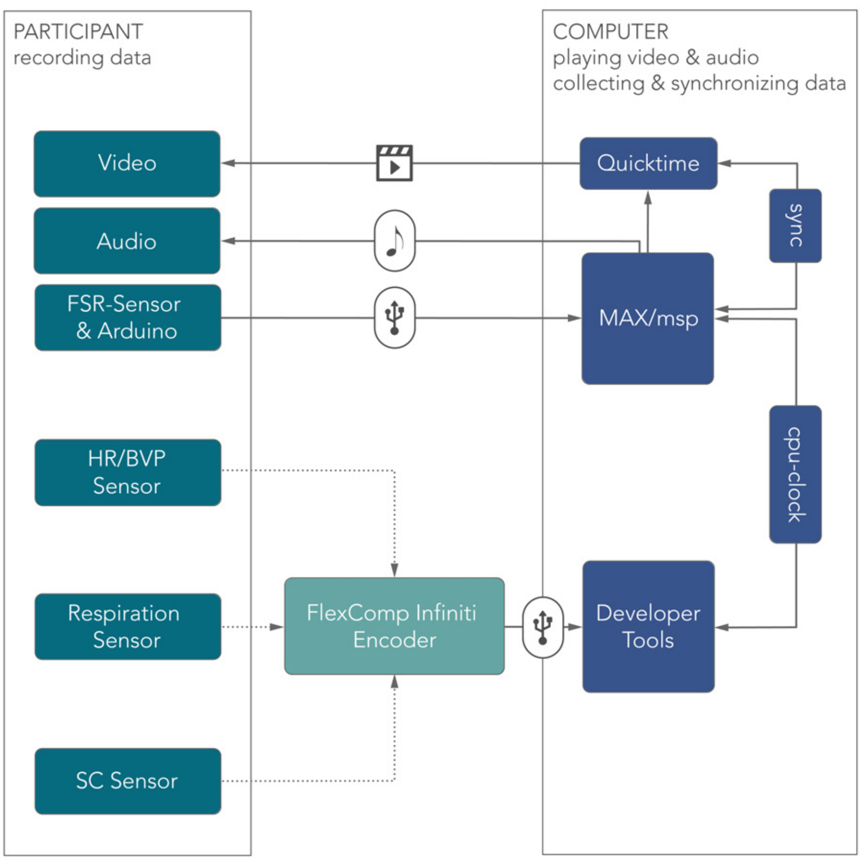

Fig. 39 Diagram of the participants' data collection

[105] FlexComp Infiniti Decoder (n.d.), accessed 3/15/2016

The within-subjects experiment with two randomized sets included 19 healthy subjects of both genders (12 male / 7 female) with an age between 19 and 32 ($\bar{x}$ 26.5). 14 participants were musicians/singers who had already or currently played or sung with a conductor; 5 were non-musicians who had never worked with a conductor.
After mounting the sensors as described above, the individual baseline was measured by playing a 3-minute video containing relaxing music and nature photographs. During the experiment the subject was instructed to follow videos of varying conducting gestures by playing a sound elicited by pressing the touch sensor. Every tapping-event induced an audio feedback, the length and force of the subject's pressure mirroring the length and volume of the evoked tone respectively. The on- and offset-time of each tapping event and the amount of pressure on the sensor were recorded. The collected sensor data was synchronized with the recorded data of the shown conducting gestures to allow further investigations.

The proceeding tasks can be subdivided into three categories:

Category 1 – Intuitive Reaction

The first category investigates the intuitive reaction to different conducting gestures. The participants are asked to follow the tempo of the conductor and to *play* – in terms of length and volume – as the conductor shows. This category includes three sub-categories:

1a) Concave, Mixed, Convex

Videos of the three gestural archetypes are shown, conducted in constant tempo (♩ = 68). Measurements of length and amount of pressure on the FSR sensor are collected, and mean and standard deviation (STD) are calculated.

1b) Dynamics & Articulation

For dynamics, two conducting gestures with identical form, but differing in size, are shown to measure differences in the applied pressure on the touch sensor. As for the effect on the articulation, the two contrasting conducting patterns (concave and convex from category 1a) are used, measuring potential differences in the length of pressure on the sensor.

1c) Predictability

Three videos of concave, convex and mixed conducting gestures with changing tempo are used to investigate the predictability of the different types of trajectories, indicated by the standard deviation (STD) from the calculated beat point.

Category 2 – Coherent task gesture combination

The second category of tasks included coherent tasks and gestures (video / instruction):

2a) Concave gesture / 'Play short notes'

2b) Convex gesture / 'Play long notes'

2c) Big gesture / 'Play loudly'

2d) Small gesture / 'Play quietly'.

In this category we focus on both factors, measurements of the touch sensor (length and amount of pressure), as well as the physiological response, collected from BVP, EDA and breathing sensors.

Category 3 – Incoherent task gesture combination

For the third category of tasks we used contrasting instructions and gestures:

3a) Convex gesture / 'Play short notes'

3b) Concave gesture / 'Play long notes'

3c) Small gesture / 'Play loudly'

3d) Big gesture / 'Play quietly'.

As in the previous category, we focus on measurements of the touch sensor (length and amount of pressure), as well as the collected data from BVP, EDA and breathing sensors. We executed every task twice in a randomized sequence to prevent order effects, and we closed the experiment with a short questionnaire, asking for background information on age, gender, profession, and musical education/experience.

3. Results

Category 1 – Intuitive Reaction

Measuring intuitive reactions on different gestural archetypes, significant differences occurred in all measured categories.

1a) Concave, Mixed, Convex

The intuitively evoked pressure on the touch sensor, which represents the produced volume of the note, differed significantly when comparing concave/convex ($p=0.00007$) and concave/mixed ($p=0.009$) gestures. The difference between convex and mixed is not significantly distinctive ($p=0.4$). The mean pressure is the highest in convex (374.8), followed by mixed with 359.5 and the lowest in concave (337.9). However, the envelope of a pressure event indicates that the difference in mean pressure should rather be described as the overall energy during one specific touch event than just mean pressure itself, as there is a longer plateau on a high pressure level in convex and mixed gestures as compared to the sharp rise and immediate decline in the concave gesture (see figure 40). While the overall energy is the lowest in case of a concave trajectory, at the same time concave has the highest mean value of the maximum pressure on the sensor (see figure 41).

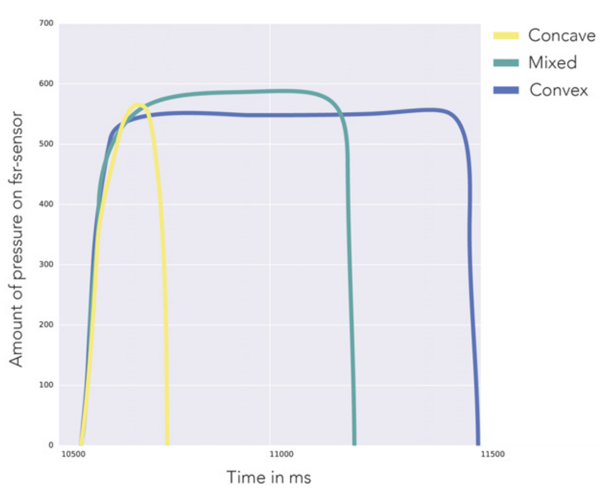

Fig. 40 Envelopes of touch events

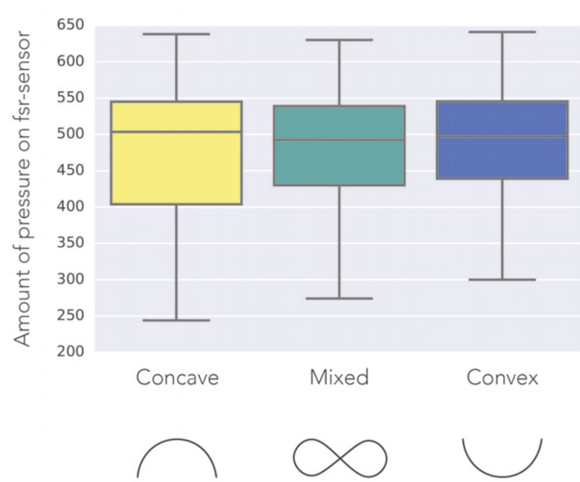

Fig. 41 Box-plots of all participants' maximum amount of pressure

Taking a look at the different groups of participants, musicians generally use more pressure than non-musicians, with the latter showing a higher standard deviation in the amount of pressure (see figure 42). For example in the case of the convex gesture, musicians pressed with an average energy of 398.2 while non-musicians reached only a mean value of 376.6. The difference in the standard deviation between musicians and non-musicians is the highest for concave gestures (musicians: 75.4/non-musicians: 115.5).

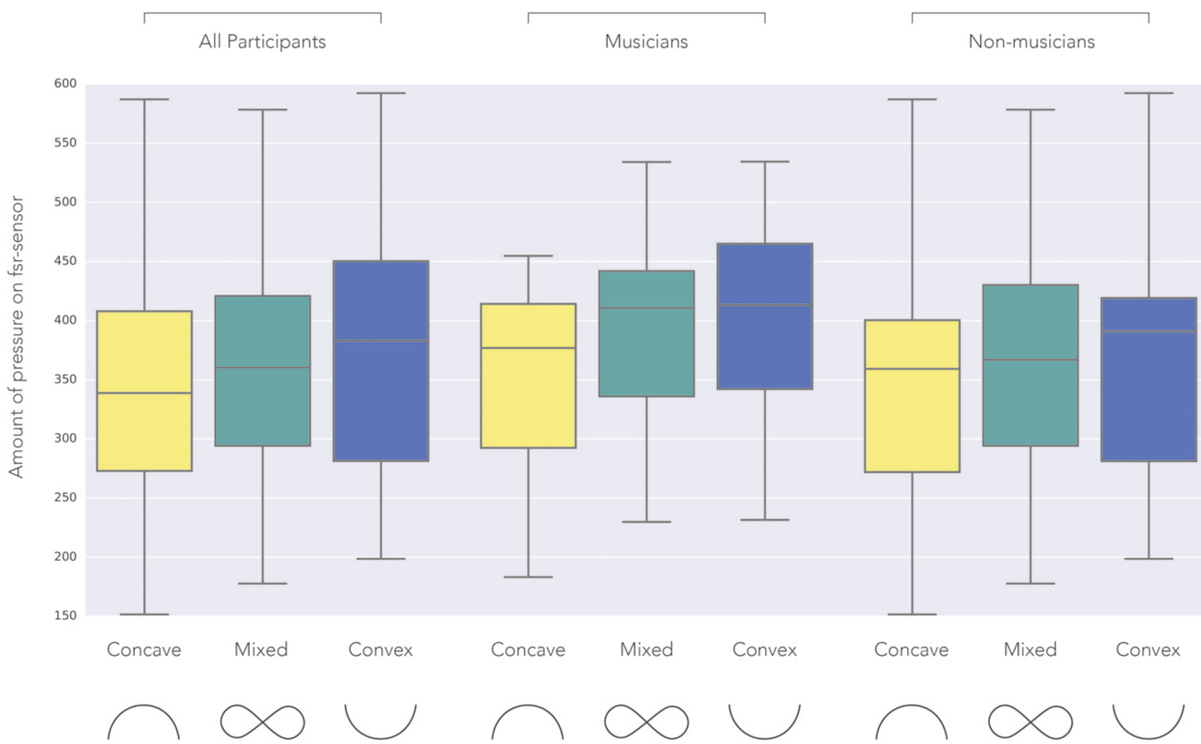

Fig. 42 Means of pressure for different groups of participants

When it comes to the length of the evoked note, differences are considerable. There were statistically highly significant differences between mean values of concave, mixed and convex as determined by a one-way ANOVA test (p = 0.0000000014). As is evident from the envelopes in figure 40, the length of the resulting note of a concave gesture (295.5 ms) is less than half of those of mixed (620.4 ms) and convex (731.8 ms). Again, standard deviations are significantly higher for the group of non-musicians compared to musicians, where specifically low deviations of 92.8 ms for concave gestures can be observed (see figure 43).

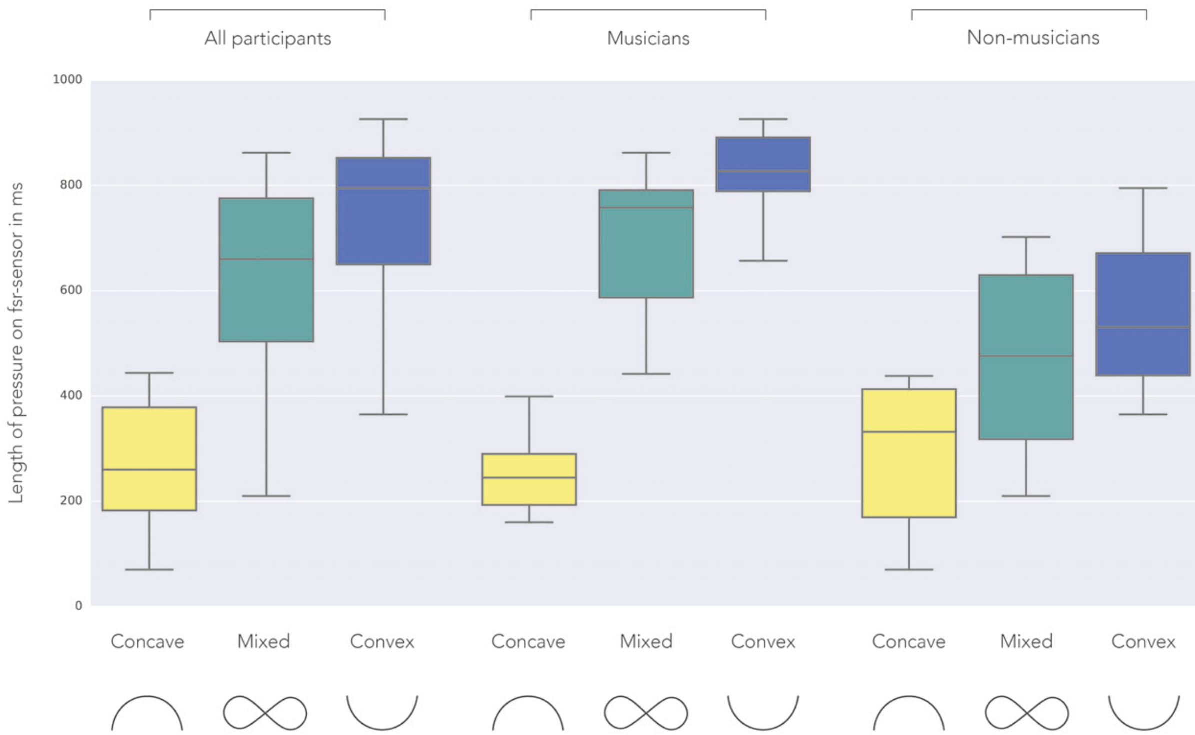

Fig. 43 Comparison of evoked length of note for different groups of participants.

1b) Dynamics & Articulation

Different forms and sizes of conducting gestures lead to highly significant differences in pressure length and force on the FSR sensor.

As for different sizes of gestures (see figure 44 on page 64), the mean pressure proves to be 293.5 mV for the small and 489.5 mV for the big gesture ($p = 0.006^{-20}$). These differences are consistent for both groups, while musicians show generally higher pressure values and a higher significance ($p = 0.007^{-15}$) in difference of force than non-musicians ($p = 0.006^{-5}$).

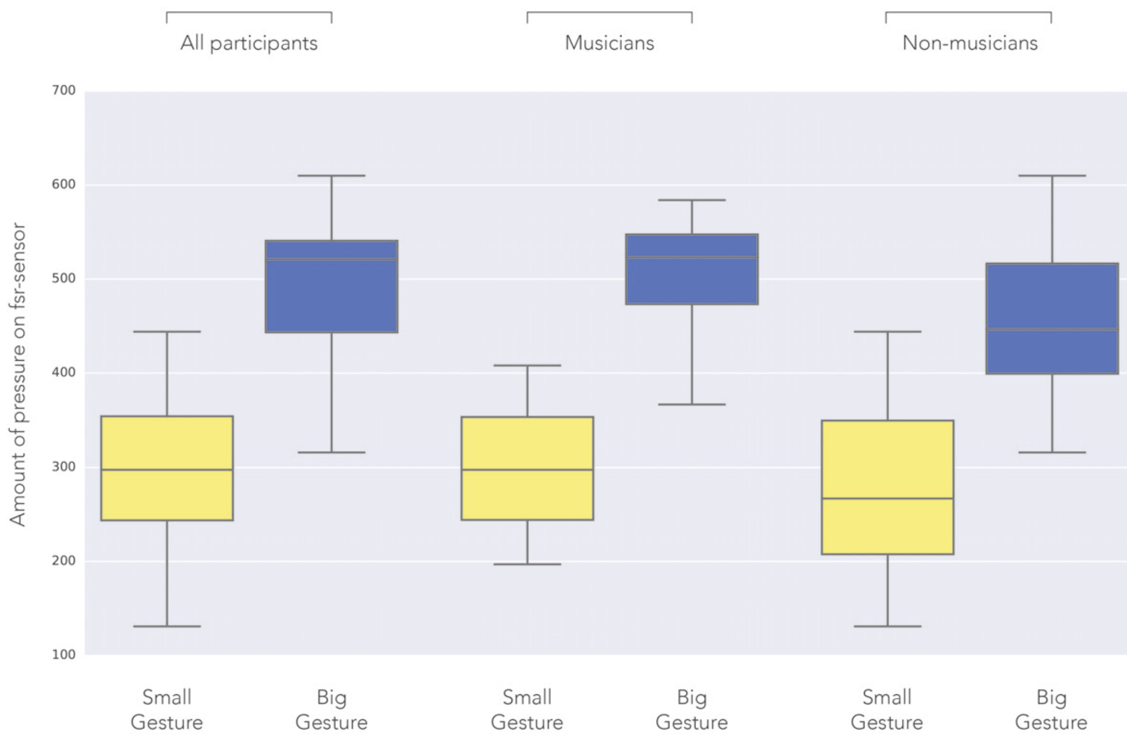

Fig. 44 Comparison of intuitively evoked volume (pressure on FSR sensor in mV)

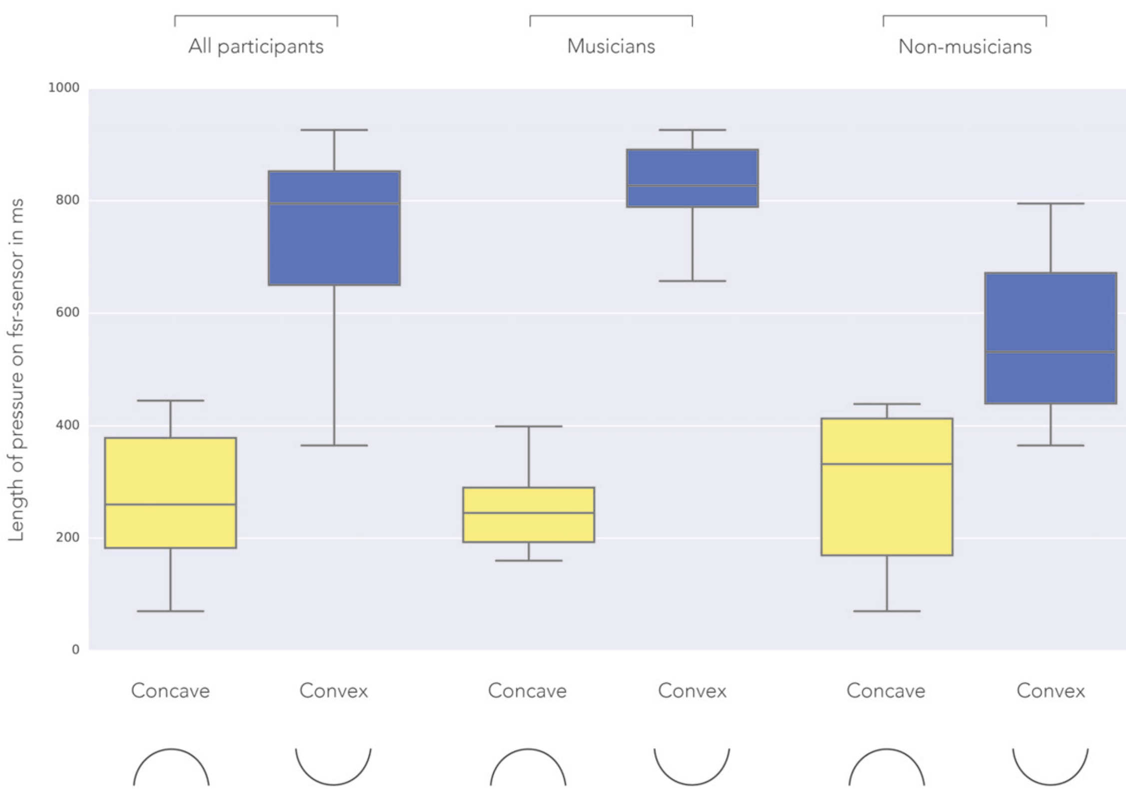

Fig. 45 Comparison of intuitively evoked length of pressure in ms

When it comes to envelope form (corresponding to the musical category articulation), the convex gesture evokes a significantly longer pressure duration than the concave gesture ($p = 0.003^{-6}$). While non-musicians show an average length of pressure of 341.7 ms for concave and 558.9 ms for convex gestures, the musicians' pressure during convex gestures is more than three times longer (796.8 ms) compared to the reaction on concave gestures with an average length of 260.8 ms (see figure 45 on page 64). Another remarkable result is the big consistency in reaction within the group of musicians to the concave gesture, showing a very low standard deviation of only 92.8 ms compared to 251.1 ms in the group of non-musicians.

1c) Predictability

Videos of concave, convex and mixed conducting gestures with changing tempo are used to investigate the predictability of the different types of trajectories. By means of a frame-by-frame video analysis we first extracted the conductor's beat points, which are located at the lower turning point of each trajectory. These beat points are then compared with the participants' onset times of each pressure event.

Figure 46 on page 66 shows clusters of delays for every single participant (= dot) for each beat of each task. The distance of the clusters on the x-axis indicates changes of tempo – the closer clusters are the faster the tempo, and vice versa. The first figure shows the delays for the concave conducting gesture: While in the beginning, when the tempo is stable, clusters are relatively compact, they become widely spread as soon as the tempo slows down (beat 8, 9 & 10). The same happens at the second deceleration around 15000 ms. The widely scattered distribution around these beats shows a lack of general precision, but the fact that some participants (see the points below the red line) press the sensor even prior to the actual visual beat, proves a lack of predictability for the concave gesture. The center figure, depicting delay clusters for mixed conducting gestures, already shows a higher consistency through tempo changes, although some participants'

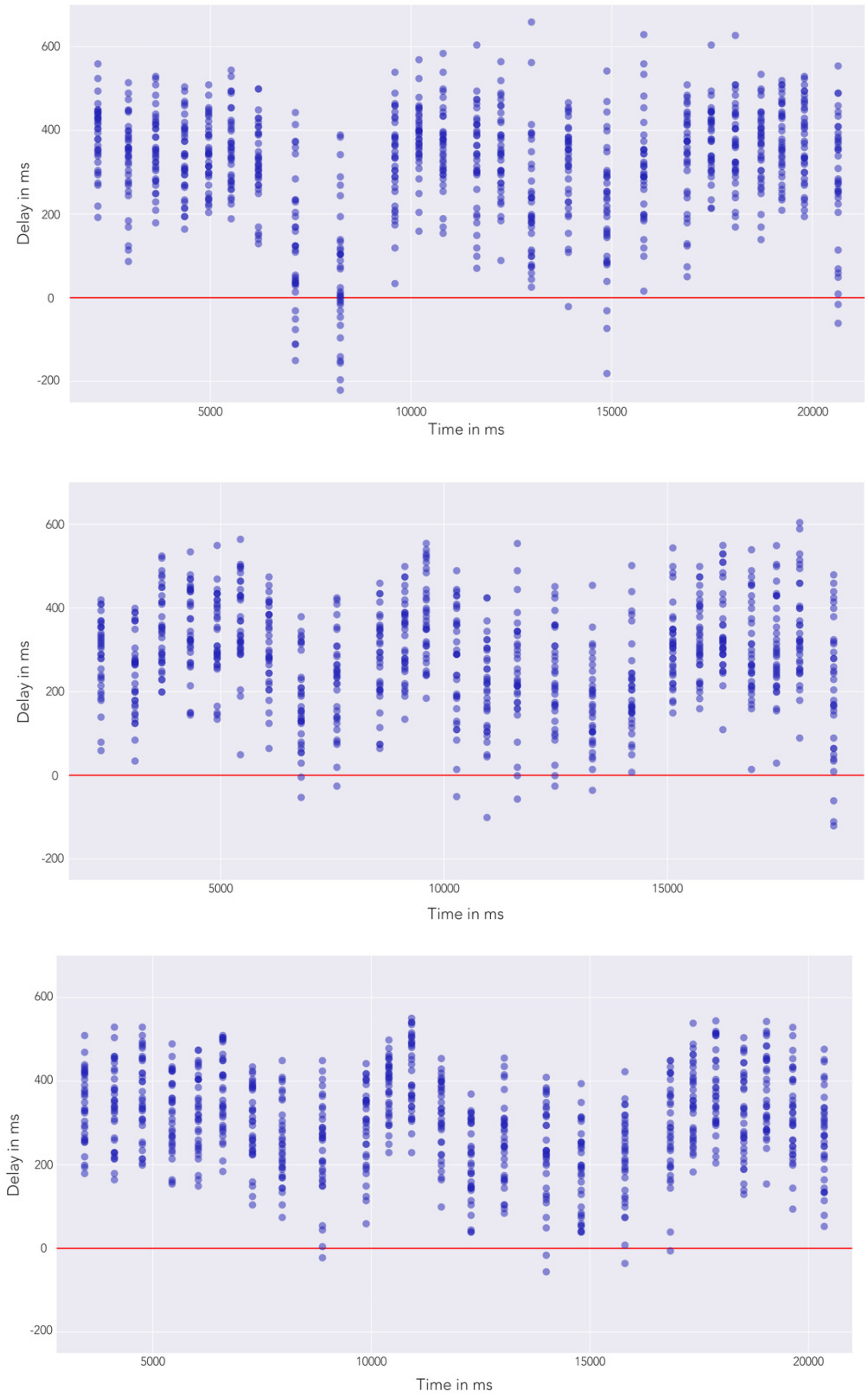

Fig. 46 Comparison of all participants' delays of concave (top), mixed (center), and convex (bottom) conducting gestures. The red line indicates the beat point. Dots above the red line have a delay, dots below show the pressure events occurring before the actual visual beat point.

onsets still occur prior to the visual beat point. The highest predictability can be found in the lowermost figure, showing convex gestures with rather high compactness; only two participants were unable to predict the deceleration.

The observed differences in predictability of the three gestural archetypes can be confirmed in significance by calculating the one-way ANOVA of the delays' standard deviation ($p = 0.04$). As seen in figure 47, the differences for the group of musicians are bigger ($p= 0.009$), especially between mixed and convex gesture, while non-musicians show a very high standard deviation of 107.5 ms for the concave gesture and similar values for mixed (90.5) and convex (92.3 ms), still significant in comparison with the concave standard deviation ($p= 0.04$), but non-significant with a one-way ANOVA test with all three gestures ($p= 0.58$).

Fig. 47 Comparison of all participants' standard deviations of delays in ms

Category 2 and 3 – Coherent and incoherent task gesture combinations

The results from category 1 and 2 support the prediction of an intuitively understandable quality of gestures concerning certain musical parameters, which – due to the high significance – can be used as a foundation for the analysis of stress in situations with contrasting respectively coherent gesture-task-combinations.

Measurements of electrodermal activity (EDA) and breathing did not show significant differences in tasks with predicted higher stress levels. The lack of response in EDA is probably due to the relatively short intervals of different tasks; longer single tasks with each gesture-task-combination could bring more consistent results. Concerning breathing amplitude, only non-significant trends could be found as discrimination from low-stress to high-stress tasks. However, breathing of instrumentalists, and especially singers, could be influenced by stress, as it plays a more "active" part in actual tone production for them than in our *one-finger-study*.

While on the one hand the heart rate (HR) showed only little difference, on the other hand changes of the heart rate variability (HRV) revealed a strong correlation with higher stress levels. Research has shown a highly significant correlation between short-term HRV analysis and acute mental stress.[106] Using the collected blood volume pulse (BVP) data, we calculated low frequency (LF | 0.04–0.15 Hz) and high frequency (HF | 0.15–0.4 Hz) powers and used the power ratio of LF/HF as an indicator for mental stress. As LF spectrum changes are associated with changes in vagal-cardiac modulation and changes in HF power with both vagal- and sympathetic-cardiac modulation, a higher LF/HF power ratio indicates a higher level of mental stress. However, only 16 participants showed useful results of the BVP measurements – data from 3 participants were insufficient and could not be used for calculations of HRV and LF/HF power ratio.

[106] Tremper 1989, Sinex 1999, Castaldo et al. 2015

Dynamics

Within the musical parameter of *dynamics* the instruction "play forte"/loudly revealed the clearest differences in HRV LF/HF power ratio (p = 0.0003). 15 out of 16 participants showed higher values of LF/HF power in cases of discrepancy between task and shown gesture. However, the amount of evoked stress differs significantly between the groups of musicians and non-musicians (see figure 48). This is reflected in a higher significance (p=0.003) for musicians, with a mean low-stress value of 1.2 and a ratio of 3.2 for the high-stress condition. Non-musicians showed a similar power ratio (1.1) in cases of low stress, but a less increased high-stress value (2.0) compared to the group of musicians, leading to a higher p-value of 0.01. Interestingly, in the case of high-stress condition, the standard deviation of the group of musicians (2.9) is much higher than it is for the group of non-musicians (1.8), indicating that some musicians seem to be trained to be somewhat more resistant to this type of stress than others.

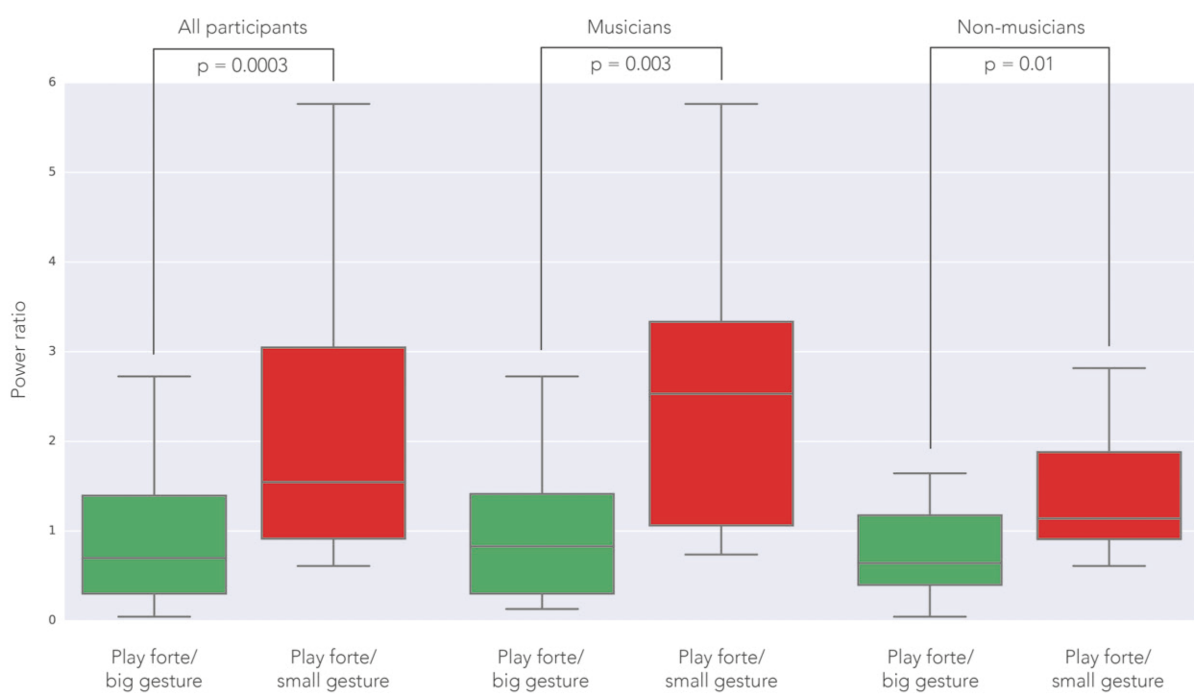

Fig. 48 Comparison of HRV LF/HF power ratio in coherent and opposed task-gesture-combinations: Play forte | small gesture for high Stress (red) and play forte | big gesture for low Stress (green).

As depicted in figure 49 the results of the second task of coherence and incoherence ("play piano"/softly) were significant, too, even though they did not reach the p-value of the previous task. Exactly as was the case with the instruction "play forte", the "play piano" task also evokes higher differences between low and high stress levels for the group of musicians (low stress 1.2 / high stress 2.2) than for the non-musicians (low stress 1.6 / high stress 1.9), resulting in a significant difference (p=0.002) for musicians, but a non-significant p-value of 0.58 for non-musicians. In contrast to the "play forte" condition, standard deviations of musicians and non-musicians are similar for the high stress task (1.4 / 1.5), while the low stress task shows a very low standard deviation of 0.6 in musicians compared to 1.5 for non-musicians.

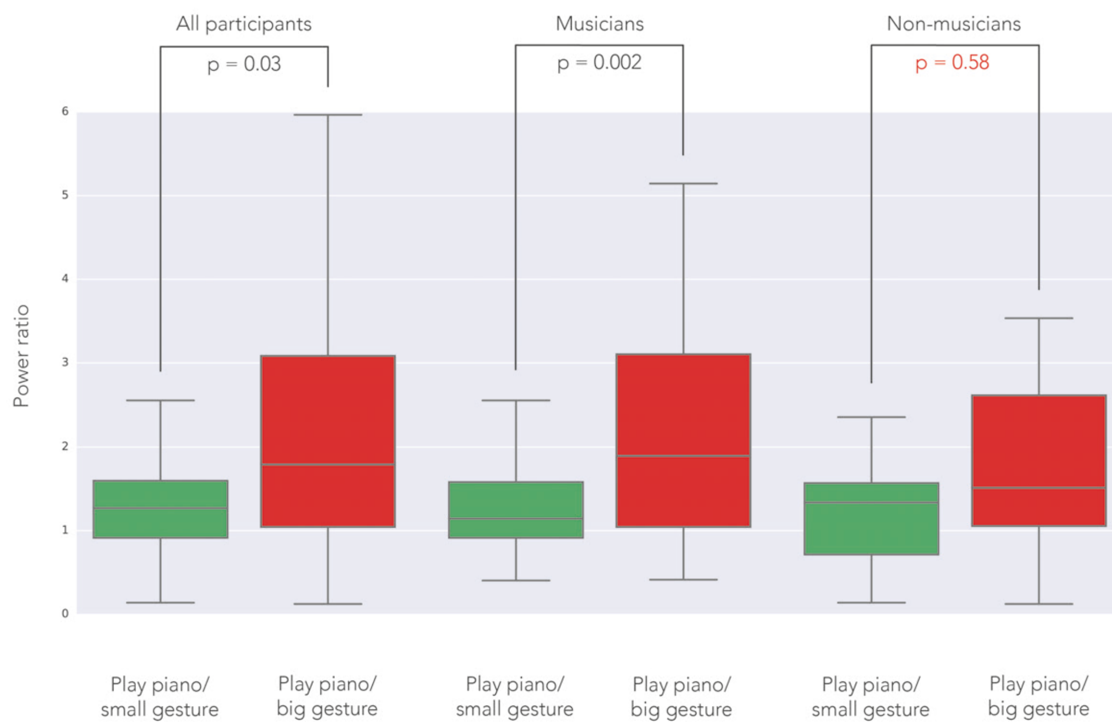

Fig. 49 Comparison of HRV LF/HF power ratio in coherent and opposed task-gesture-combinations: Play piano I big gesture for high stress (red) and play piano I small gesture for low stress (green).

Articulation

The combination of the instruction “play staccato” while following a convex or a concave conducting gesture, showed the most consistent stress reactions (p = 0.0003). All 16 participants show higher LF/HF power ratios under the stress inducing condition. As for all other tasks, musicians again show a higher significance in the consistency of their stress reaction. In contrast to the tasks of contrasting dynamics, the highest stress reaction in the ”play staccato” task can be found in the group of non-musicians with a value of 3.2, compared to 2.5 in musicians. The standard deviation in the case of the low-stress task is very low at 0.6 for both groups, while it is much higher for non-musicians (1.9) compared to 1.2 in musicians for the high-stress condition.

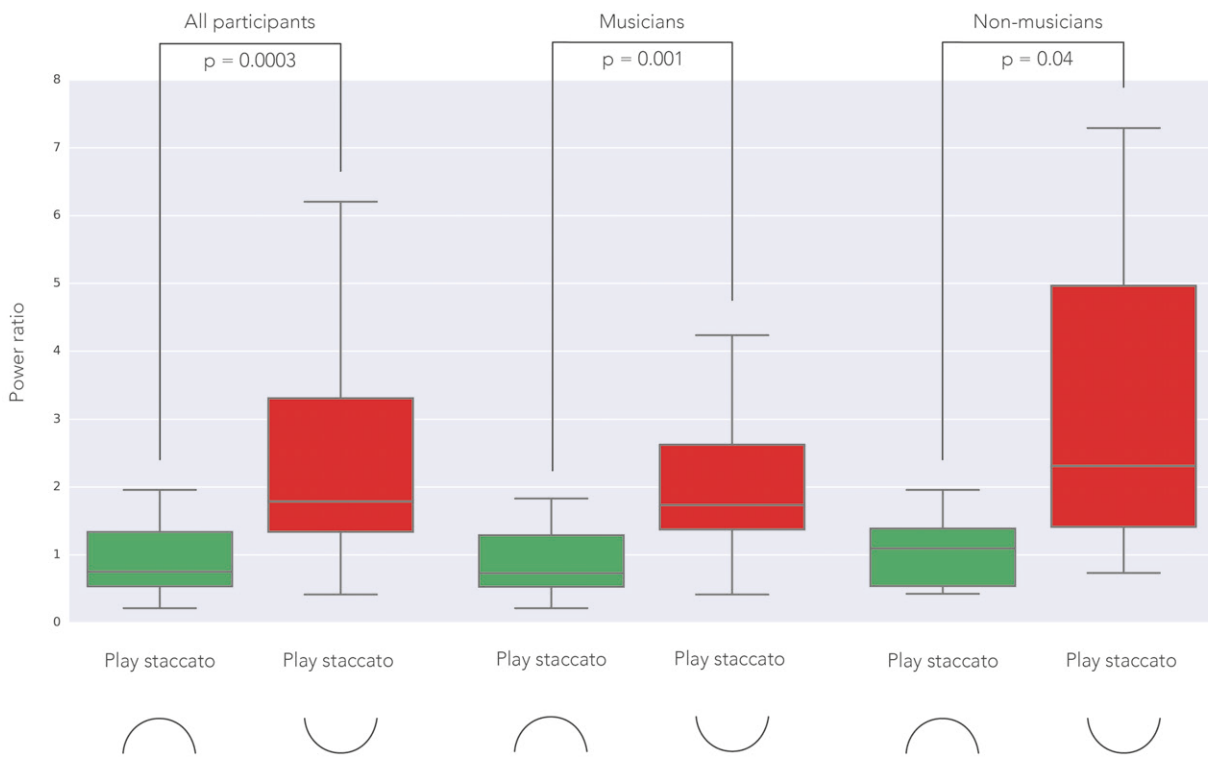

Fig. 50 Comparison of HRV LF/HF power ratio in coherent and opposed task-gesture-combinations: play staccato | round gesture for high Stress (red) and play staccato | jagged gesture for low Stress (green).

The "play legato" task also showed convincing consistencies in change of power ratios, but the differences between coherent and opposed instruction-gesture-combination in this task were smaller than in the previous one (p = 0.001). Furthermore, compared to all other stress inducing tasks, the "play legato" condition evokes the least amount of stress with an overall mean of 2.0. Between the two groups of participants, differences in values and standard deviations are rather small, and can only be found in the results of the stress inducing condition with a power ratio of 2.1 (STD 1.9) for non-musicians and 1.9 (1.2) for musicians.

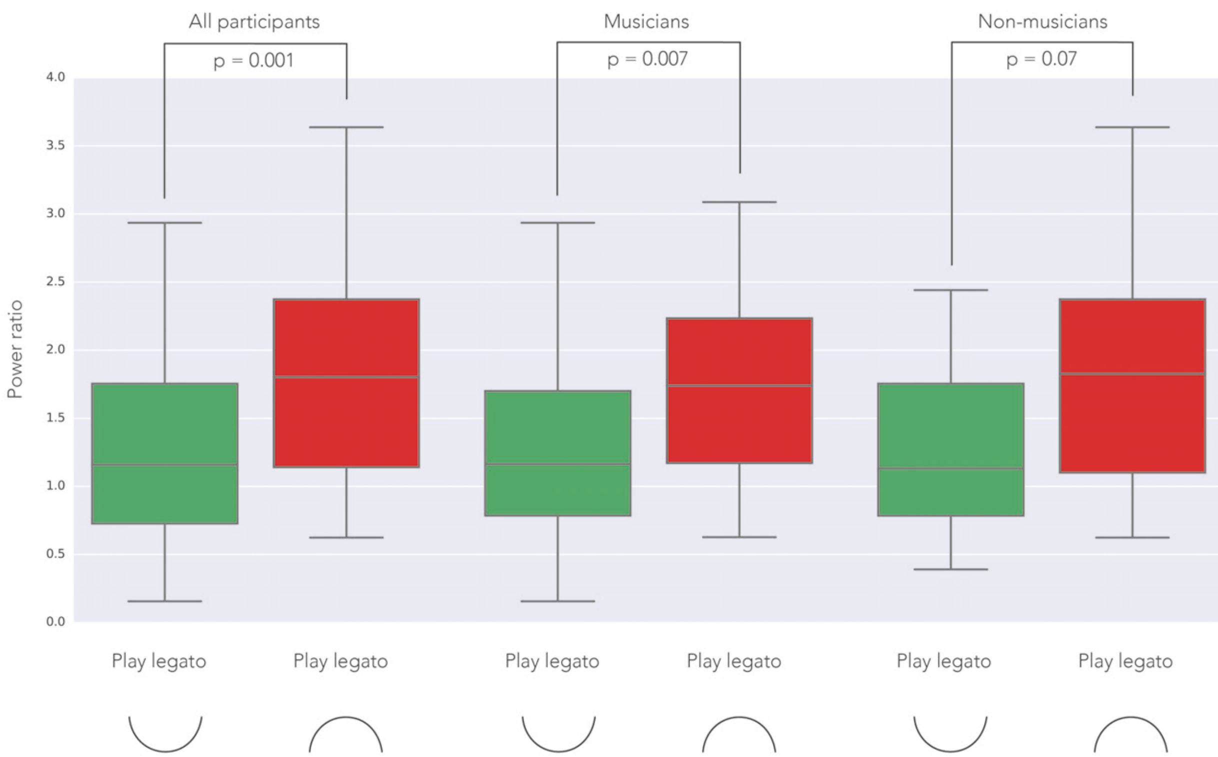

Fig. 51 Comparison of HRV LF/HF power ratio in coherent and opposed task-gesture-combinations: play legato | concave gesture for high Stress (red) and play legato | convex gesture for low Stress (green).

Differences in length and amount of pressure

All resulting reactions of incoherent instruction-gesture-combinations deviated negatively from the results of the corresponding coherent combination. The most striking result can be found in the "play legato" task, showing a highly significant difference (p=0.00003) in the lengths of the evoked pressure on the FSR sensor in case of a discrepancy between instruction and gesture (see figure 52). Although both tasks should theoretically elicit the same length of pressure, the participants seem not to be able to hold the note as long with the concave gesture (654.3 ms) as with the convex gesture (706.7 ms). A similar reaction can be found in the "play piano" task, evoking a significantly higher pressure (p=0.03) when accompanied by a big gesture. For both the "play staccato" and "play forte" task (see figures 52 and 53), there is no significant deterioration in case of the incoherent gesture.

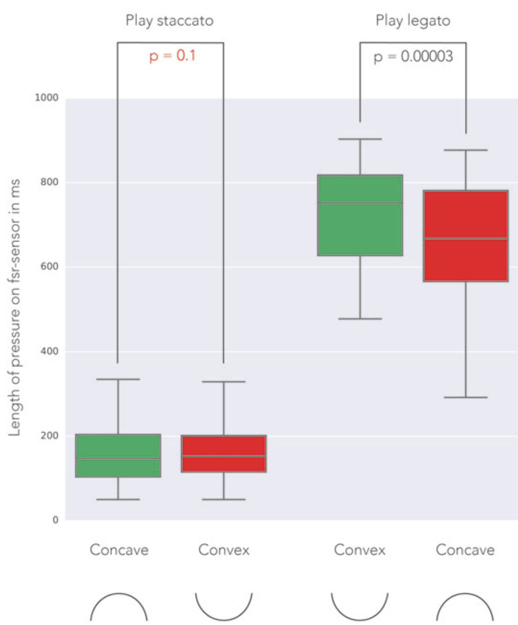

Fig. 52 Comparison of length of tone in coherent and opposed task-gesture-combinations for articulation.

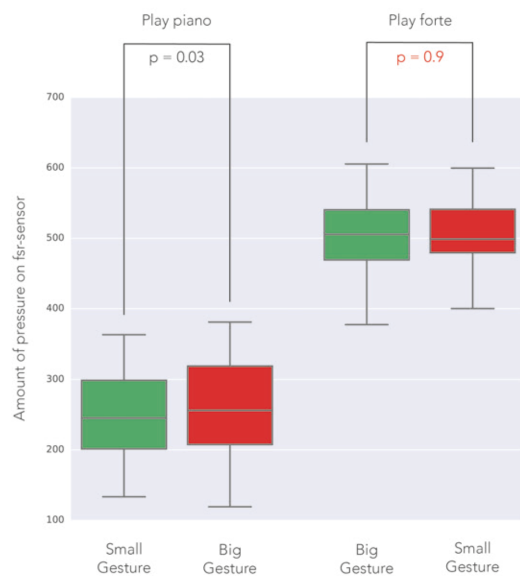

Fig. 53 Comparison of pressure in coherent and opposed task-gesture-combinations for dynamics.

4. Discussion

The main purpose of the presented study was to explore the impact of different gestural archetypes on the musician's body and the sounding result. In the first part of the study, we investigated the reaction of participants on three archetypal conducting gestures with different shapes of trajectories. The results correspond with Köhler's findings of non-arbitrary mappings between speech sounds and the visual shape of objects and confirm, as maintained by Schuldt-Jensen[107], suggesting that such correlation also exists between conducting gestures and the elicited tone. Our results scientifically document for the first time the spontaneous and consistent relationship between certain shapes of conducting gestures and the resulting articulation, as well as a significant correlation between size of gesture and evoked volume. Interestingly, different shapes of gestures do not lead to significant difference in terms of loudness of the resulting tone, but the envelope of the evoked tones varies significantly, in that there is a big difference in intuitively evoked length of sound. The loudness of the note is primarily influenced by the size of the gesture. These findings could be of direct practical relevance, especially for the field of conducting pedagogy; for example, in view of the fact that there are significant differences in the intuitive reaction to concave versus convex conducting patterns, it would be especially interesting to further analyze teaching books on conducting presenting a combination of both types (see figure 54).

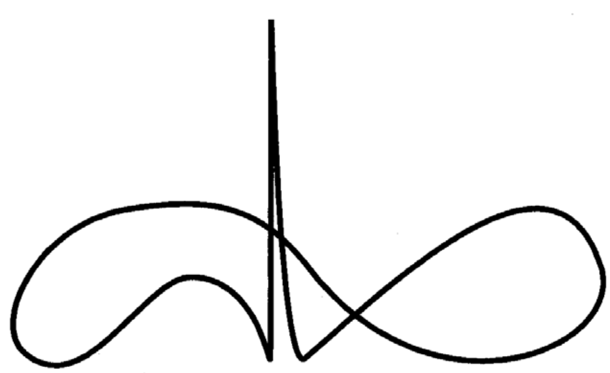

Fig. 54 4-beat-pattern as taught by Robert Göstl

[107] Schuldt-Jensen 2016

Another important attribute of successful conducting technique is the predictability of the shown gesture. Especially when it comes to delicate musical elements, such as a pizzicato or a subtle unison cue, and to tempo changes, crucial for musical phrasing, an unpredictably shaped gesture immediately deteriorates an interpretation, because the conductor loses control over the timing and the onset-offset-envelope. In order to measure differences in predictability of conducting gestures, we created tasks with a changing tempo and calculated the onset-delays of the participants' touch-events. While refuting Serrano's[108] findings, the results confirm Schuldt-Jensen's[109] analyses of the studies by Luck et al.[110] as well as conducting patterns in general, to the effect that convex conducting gestures show the highest predictability as opposed to mixed and concave gestures, which show a higher standard deviation especially in sections of deceleration.

The analysis of blood volume pulse data shows a significantly higher stress level in all cases of discrepancies between a given instruction and the accompanying gesture. The negative deviations from the sounding result of the coherent combination, especially in case of articulation, seem to be caused by a relative dominance of the perceived haptic qualities of the gestures, which are obviously impossible to suppress. The attempt to play exactly as the instruction demands when gestures are incoherent, seems to increase mental stress, while "disobedience" concerning the given verbal instruction seems to be less stressful, as could be seen under the "play legato" condition. Thus, it might be concluded that gestures are more essential than verbal instructions.

An important implication of these findings is that not only general working conditions but also a lack of consistency between shown gesture and given verbal instruction induces negative stress, and – over a longer period of time – could cause chronic physical and psychological illness.

[108] Serrano 1993

[109] Schuldt-Jensen 2016

[110] Luck and Toiviainen 2006, Luck and Sloboda 2006, Luck and Nte 2008

IV VIOLIN STUDY

1. Preliminary Analysis & Study Design

A large proportion of the myth around the conductor is inextricably linked to his individual and inexplicable influence on the sound of an orchestra. In this context, many reports of the conductor's unique influence on the orchestra exist. For example, Arthur Nikisch is said to have *"had the uncanny ability to get a ravishingly beautiful sound out of an orchestra without saying a word."*[111] A commonly used explanation of a specific sound of an orchestra is the *aura* of a charismatic conductor. The most famous example is probably Wilhelm Furtwängler, who was known to change the orchestra's sound just by entering the room, even when someone else was conducting.[112] Bertrand de Billy refers to an inherent sound every conductor carries within himself: *"As conductors, we do not produce sound by ourselves. But everybody has his own sound. This is more than only a chemical-physical phenomenon."* [113] Opera expert Marcel Prawy says of Carlos Kleiber: *"It is almost a mythic-hypnotic control over the action in the orchestra by a genius personality".*[114] Recent books on the role of the conductor refer to more scientific concepts, such as *mirror neurons* or *emotional contagion,* as an explanation for the apparently inexplicable influence of conductors on the sound of an orchestra.[115] Unfortunately, so far no research exists on conductor-musician communication in these fields. Wolfgang Hattinger concludes that there are no rationally explicable or controllable energies and transferences in play, But, besides aura, personality and *emotional contagion,*[116] could gestures themselves also have an influence on the sound?

[111] Seaman 2013, p. 250

[112] Lawson 2003, p. 119

[113] Billy 2013, p. 5 („Wir Dirigenten erzeugen selbst keinen Klang. Aber jeder hat seinen Klang. Das ist mehr als nur ein chemisch-physikalisches Phänomen.")

[114] Hattinger 2013, p. 223 („Es ist beinahe eine mystisch-hypnotische Einflussnahme einer genialen Persönlichkeit auf das Geschehen im Orchester")

[115] Hattinger 2013, p. 227-237

[116] Hatfield 1994

With the previously described touch-sensor study we could already prove an influence of different shapes and sizes of conducting gestures on the length and volume of the elicited note. But do conducting gestures also influence the sound quality of proficient instrumentalists? After confirming the hypothesis of conducting as an intuitively understandable language evoking analogic reactions, this study attempts to explore measurable differences in muscle tension and sound quality in musicians.

Violinists represent the largest instrumental group of orchestra musicians. As target group for our second experiment they are especially interesting, because all main body parts involved in the process of playing the violin are visible and accessible for sensors. Moreover, the violin offers a comparatively open sound configuration; timbre varies depending on the bow's speed, pressure, angle, and position of contact, as well as on the left hand's finger pressure on the strings.

Form of Trajectory – Concave, Convex & Mixed

Based on the findings of the touch sensor study (see previous chapter), we decided to measure potential differences in intensity and muscle-tension for concave, convex and mixed conducting gestures. Using the video recordings from the touch sensor study to ensure exactly the same conditions, we asked the participants to use the third finger to play a d'' on the a-string in half notes, following the shown gestures.

Hand Posture – Supination & Pronation

Another interesting detail to investigate is the conductor's hand posture. When observing different hand postures of famous conductors, four variations can be found: the palms of the hands either face downward (*pronation*), sideward (*neutral*), upward (*supination*) or both hands are showing different hand postures (see Figure 55-58 on page 78).

Fig. 55 Herbert von Karajan – neutral hand posture

Fig. 56 Wilhelm Furtwängler – pronation

Fig. 57 Christian Thielemann – supination

Fig. 58 Sir Simon Rattle – mix of supination and pronation

Interestingly, only a few teaching books on conducting give specific advice concerning a recommended hand posture. *"Keep your palms basically facing the floor […]"*[117] is Boonshaft's advice, without giving any further explanations. Colson also suggests that *"[…] the right-hand palm should be parallel to the floor; otherwise the conducting motion to the ictus becomes unclear."*[118] But he does not provide an explanation of why this is the case. It is quite remarkable how some teaching books just show pictures of *wrong* and *right* hand postures without any comment or explanation (see figures 59 and 60 on page 79).

[117] Boonshaft 2006, p. 122
[118] Colson 2015, p. 4

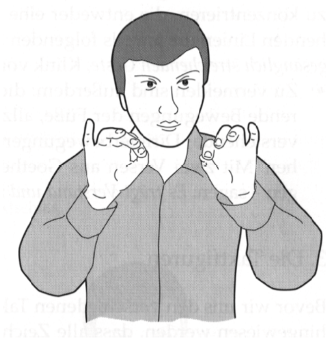

Fig. 59 Correct hand posture (Wierød 1989)

Fig. 60 Good hand posture (Bimberg 1989)

From an anatomical perspective, there are major differences between both extremes – *supination* and *pronation*. As figures 61 and 62 show, *pronation* is a result of a lower arm rotation making the palm face downwards. In this position both forearm bones (*radius* and *ulna*) are crossed. In *supination*, the so-called *supinator* muscle causes the forearm to rotate toward the outside, the palm facing upwards, thus bringing *radius* and *ulna* back to a parallel position.

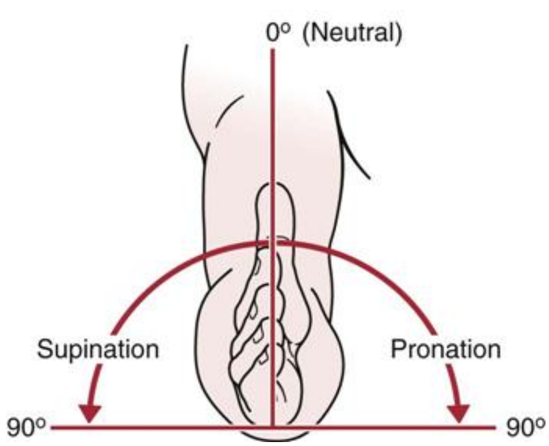

Fig. 61 Pronation, neutral and supination

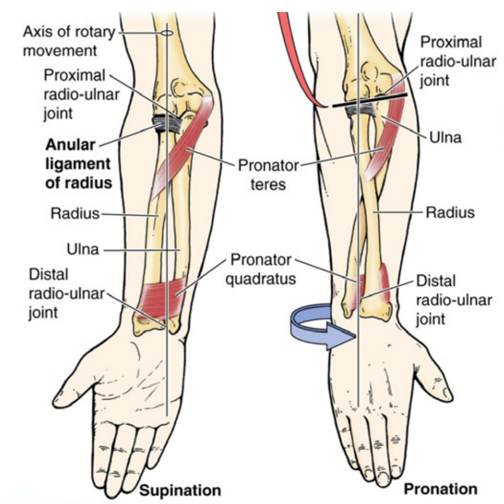

Fig. 62 Anatomy of supination and pronation

In order to investigate potential differences in reaction on *pronated*, *supinated* and *neutral* hand positions, we recorded conducting gestures with all three hand postures, using the same (*convex*) form of trajectory conducted in constant tempo (= 68).

The Fermata

When it comes to conducting a *fermata*, two contradicting approaches can be found in teaching books: The first method suggests to completely stop the movement on the beat where the fermata starts, and then hold the position as long as the conductor wants the note to sound. As McElheran writes:

> *"Simply hold the hand still when you come to the fermata, letting the note continue as long as you wish."*[119]

Similar descriptions can be found in Farberman[120], Freeman[121], Galkin[122] and Schroeder[123]. In contrast, the second approach recommends to continue with a slow movement during the fermata to support a sustained sound:

> *"When indicating a fermata the concept of 'travel' should be employed. Sound is motion and motion is movement. The baton and/or hand(s) should display movement during the conducting of a fermata as opposed to a 'frozen' statue-like pose."*[124]

Also Phillips[125], Schuldt-Jensen[126] and Colson[127] mention the importance of continuous movement in the fermata-gesture. In order to explore potential differences in muscle tension and sound quality, we presented participants with both versions of the fermata, asking subjects to play a fermata as shown by the conductor.

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[119] McElheran 2004, p. 85
[120] Farberman 1999, p. 124
[121] Freeman 2015, p.124
[122] Galkin 1988, p. 323
[123] Schroeder 1889, p. 26
[124] Maiello et al. 1996, p. 81
[125] Phillips 1997, p. 179
[126] Schuldt-Jensen 2008, p. 4
[127] Colson 2012, p. 459

2. Data Collection

The presented study was approved by the Committee on the Use of Humans as Experimental Subjects (COUHES) at the Massachusetts Institute of Technology.
Before taking part in the study, all subjects were informed of purpose and procedure of the study and informed consent was obtained.

Recording the Conductor

Additionally to the recorded *concave*, *convex* and *mixed* conducting gestures taken from the touch-sensor study, we asked the same conductor to be recorded with additional gestures under the same conditions as described in the previous chapter. In accordance with the touch-sensor study, two *MYO Armbands*[128] were placed on the right lower and upper arm to record muscle-tension of the conducting movements,

Hand Posture – Pronation, Supination and Neutral

For different hand postures as seen in figures 63-65, we recorded convex 2-beat conducting gestures in constant tempo (♩ = 68) in separate tasks for each of the different forearm rotations.

Fig. 63 Pronation

Fig. 64 Supination

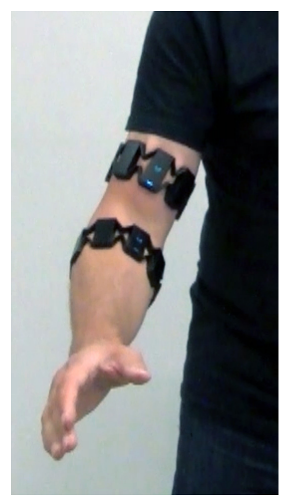

Fig. 65 Neutral

[128] Myo Gesture Control Armband (n.d.), accessed 03/14/2016

Fermata – with and without movement

For the two different types of fermatas we asked the conductor to perform both versions in the same time frame to ensure comparability. Figure 66 shows an overlay of first and last frame of the fermata without movement; only a minimal movement at the thumb can be observed while the forearm and hand remains completely static. The overlay of figure 67 shows first and last frame of the fermata with movement, with a red arrow describing the direction of movement. Both fermata versions have a length of 7.5 seconds.

Fig. 66 First and last video frame of the fermata without movement

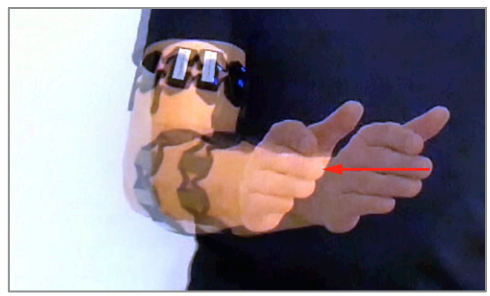

Fig. 67 First and last video frame of the fermata with movement

Recording the participants

For the participants, the experimental setup consisted of a screen, showing videos of the prerecorded conducting gestures and a *Zoom H2* device to record audio in 44100 Hz stereo, 32 bit wave-format. As orchestra musicians usually play seated, we also asked our participants to sit during the experiment. While following a protocol of single tasks, the participants wore three *MYO Armbands*, one on the right and left forearm respectively and the third on the right upper-arm. As shown in the diagram (figure 68 on page 83), *Max*/MSP[129] was used to start the conducting videos synchronized with the data-collection from the *MYO Armbands*. The data stream was then sent to the computer through a

[129] Cycling '74: Max/MSP (n.d.), accessed 3/16/2016

Bluetooth connection. Via the application *MyOSC*[130] we forwarded raw data received from the *MYO* armbands as by *Open Sound Control* (OSC) messages to *Max/MSP*, where we time stamped and synchronized all data to allow a comparison with the data collected from the conductor's movements during the first stage of the study.

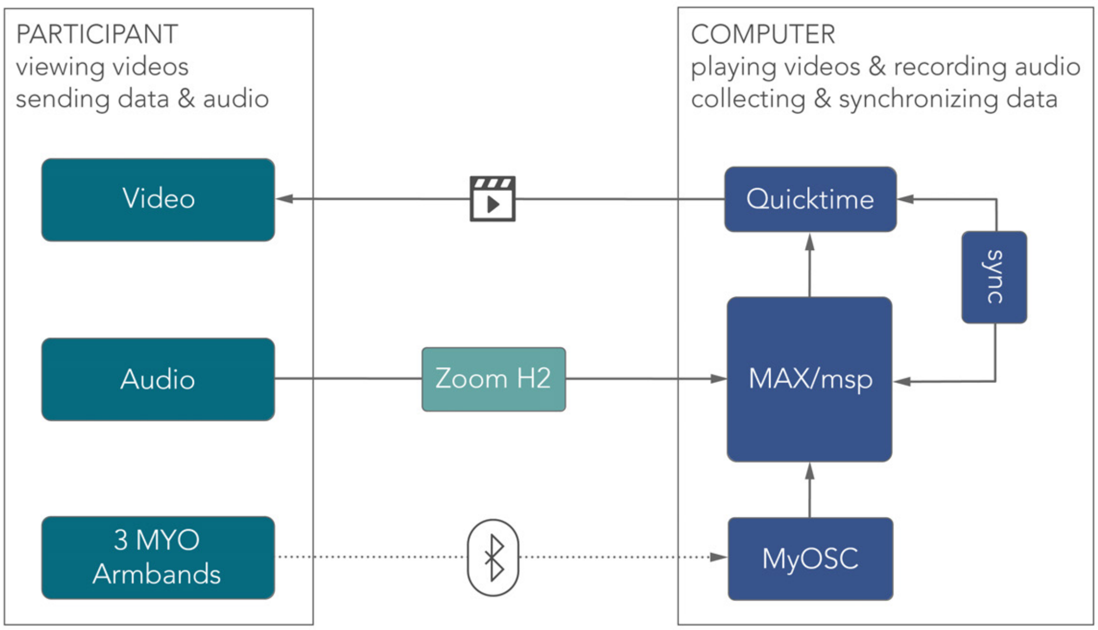

Fig. 68 Diagram of the participants' data collection

The within-subjects experiment with two randomized sets included 8 healthy subjects of both genders (1 male / 8 female) with an age between 19 and 63 ($\bar{x}$ 31). All 8 participants are active violinists with at least 8 years of experience of playing under a conductor; 4 participants are professional violinists and members of professional symphony orchestras, 4 play on a semi-professional level.

After mounting the 3 *MYO* armbands, the subject was instructed to follow videos of varying conducting gestures by playing a d'' with the third finger on the a-string in half notes. The

[130] Kuperberg 2016, accessed 3/15/2016

recorded audio and collected sensor data was synchronized with the recorded data of the conductor to allow further investigations.

The proceeding tasks can be subdivided into three categories:

Category 1 – Concave, Convex and Mixed

The first category investigates the intuitive reaction to different forms of conducting gestures in terms of sound quality and muscle tension.

Category 2 – Pronation, Supination and Neutral Hand Posture

With different forearm rotations we aim to explore potential influences of hand postures on the sound quality and muscle tension of conductor and musician.

Category 3 – Fermata

This category is designed to show possible differences in sound quality in cases of a fermata with respectively without movement.

We executed every task twice in a randomized sequence to prevent order effects, and we closed the experiment with a short questionnaire, asking for background information on age, gender, profession, and musical education/experience.

4. Results

Category 1 – Concave, Convex and Mixed

Measuring intuitive reactions on different gestural archetypes, significant differences occurred in the measured intensity[131] of the evoked tone.

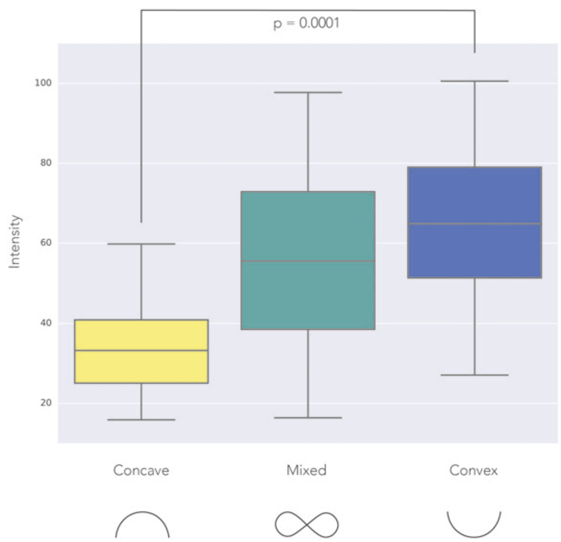

Fig. 69 Intensity comparison of evoked tone.

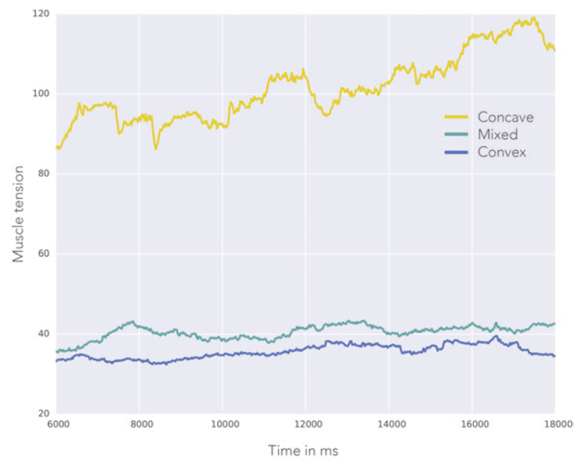

Fig. 70 Muscle tension in the conductor's right forearm.

By means of the *Sonic Visualiser*[132], we calculated the intensity of the signal, i.e. the sum of the magnitude of the FFT bins of 7 sub-bands. As shown in figure 69, the highest average intensity was induced by a convex gesture (66.4), followed by mixed (56.7) and concave (34.1). The observed differences in intensity of the three gestural archetypes can be confirmed in significance by calculating the one-way ANOVA ($p = 0.0001$). These results confirm the findings of intuitively evoked volume in form of pressure in the touch-sensor study (see page 61–62). Interestingly, an analysis of the conductor's muscle tension in the

[131] Lu, Liu and Zhang 2006, p. 8-9

[132] Sonic Visualiser (n.d.), accessed 03/04/2016

right forearm shows contrary results (see figure 70 on page 85): The conductor uses the highest average muscle tension with the concave gesture (90.2), followed by mixed (41.5) and convex (33.7). Although the resulting intensity is consistent trough all participants, measurements of muscle tension of the musicians do not give significant results.

Category 2 – Supination, Pronation and Neutral

Different forearm rotations, conducted with the same (convex) trajectory, show significant influences on the evoked intensity (see figure 71).

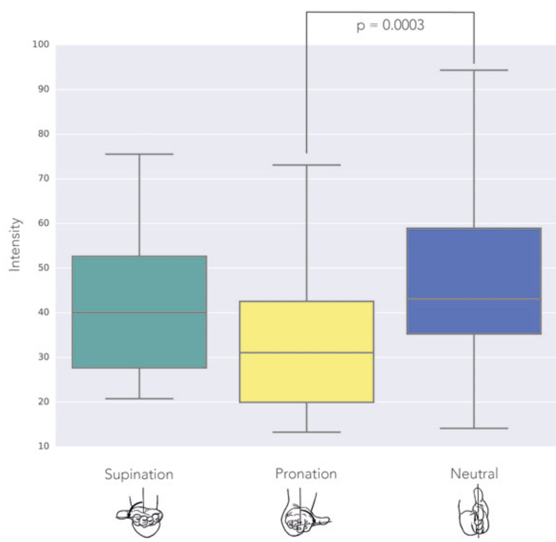

Fig. 71 Intensity comparison of evoked tone.

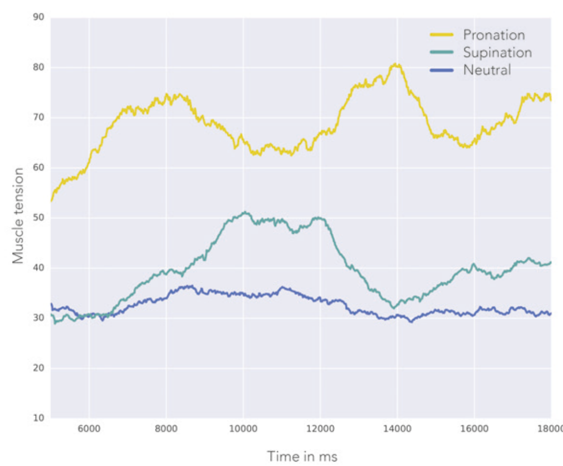

Fig. 72 Muscle tension in the conductor's right forearm.

Differences between neutral hand posture and pronation show the highest significance with p=0.0003. Also, the divergence between neutral and supination is significant (p=0.02), while the comparison of the results in cases of supination and pronation is non-significant (p=0.1). As observed in category 1 as well, measurements of the conductor's muscle tension in his right lower arm show contrasting results: as depicted in figure 72, the neutral hand posture shows the lowest muscle tension in the conductor's forearm while apparently evoking the highest intensity in (the violinist's) sounding reaction. At the same time, a high muscle tension in pronation evokes the lowest intensity. As in Category 1, although highly consistent in the resulting intensity, the corresponding measurements of muscle tension of participants do not give significant results.

Category 3 – Fermata

Measurements of intensity in the two different versions of the fermata show significantly (p=0.01) higher values (mean intensity: 20.8) for the fermata with movement compared to the static version (mean intensity: 17.7) (see figure 74). Figure 73 depicts small, but significant differences in mean muscle tension of the conductor indicating a slightly higher value for the fermata with movement.

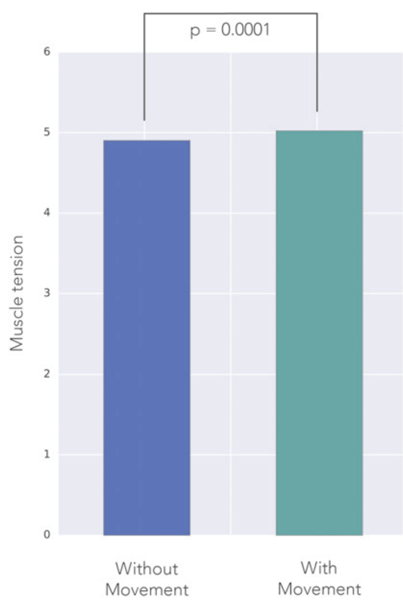

Fig. 73 Muscle tension in the conductor's right forearm.

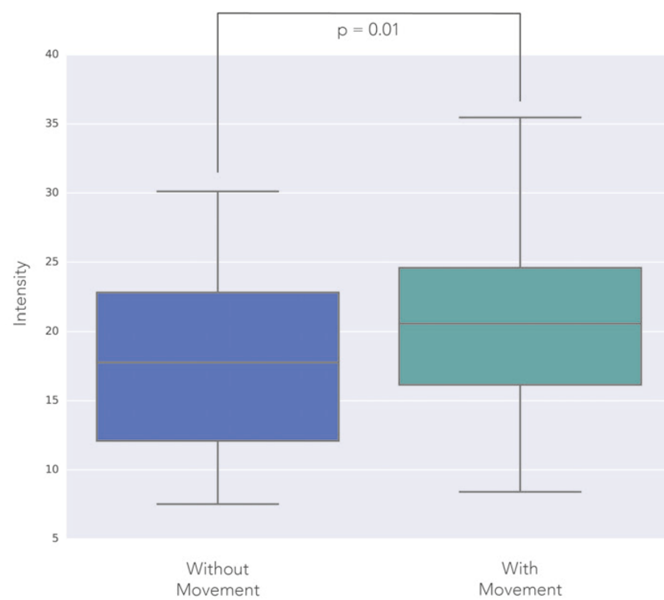

Fig. 74 Intensity comparison of evoked tone.

The movement of the conductor's arm during a fermata seems to not only have an influence on the mean intensity, but also the envelopes of intensity over time differ considerably: The version with movement starts with a high intensity that remains relatively stable until the middle of the fermata, before decreasing until the end of the note (see figure 75). Figure 76 shows a typical fermata without movement, starting already with a lower intensity than the other version; a drop of more than 30% occurs between second 1 and 2, followed by a rise until the end of the note. Furthermore, the version with movement appears to be smoother than the fermata without movement with its heavy fluctuations.

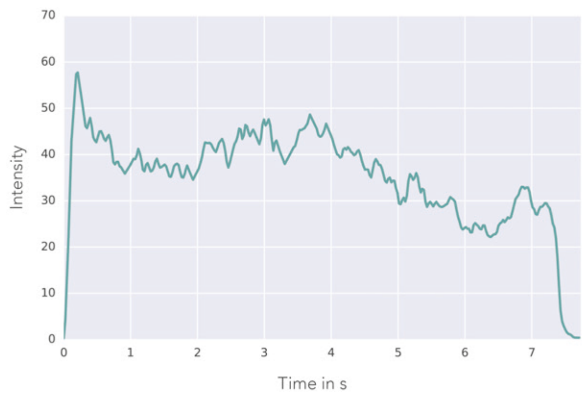

Fig. 75 Fermata with movement

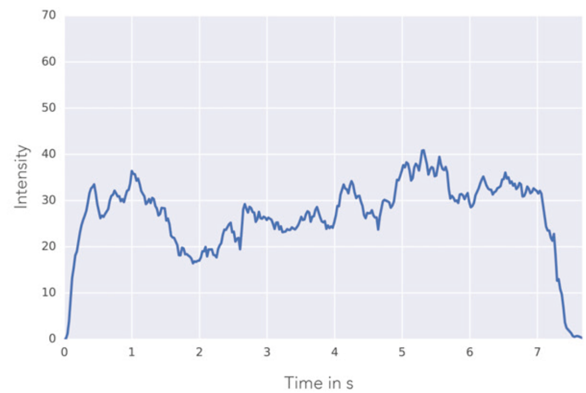

Fig. 76 Fermata without movement

5. Discussion

The presented study aimed at exploring the impact of different conducting gestures on muscle tension of the musicians as well as the resulting sound. The results show significant findings in all investigated categories for both the conductor's muscle tension and the intensity of the evoked sound. However, the outcome has a number of limitations: Firstly, due to the small number of participants, no significance could be reached when measuring the violinists' muscle tension. Secondly, in addition to the individual and slightly varying playing techniques of the participants, every one of them used their own instrument. Both of these factors presumably led to inconsistencies in the measured muscle tension as well as the sound quality. In future studies, the same instrument should be used for all participants, and the individual differences in instrumental technique – if unavoidable – should be documented and be taken into consideration during data analysis.

The reactions on concave, convex and mixed conducting gestures show significant differences in intensity of the evoked tone; interestingly, the amount of muscle tension involved in the production of the conductor's movement seems to be in inverse proportion to the intensity of the resulting tone. Furthermore, trajectories with a natural gravitational pendulum movement, executed through lifting the arm and then releasing the potential energy into the trajectory, such as convex and (partly) mixed, apparently evoke a higher level of intensity than the concave gesture with its bouncing movement against gravity.

The results of the second category show that not only the form of the conducting gesture leads to differences in intensity. Also, different forearm rotations used with the same (convex) form of trajectory influence the intensity of the induced tone significantly. Both of the standard rotations (prescribed in many books on conducting) pronation and supination (see page 86) evoke a lower intensity, compared to a neutral hand posture.

For the third category, though differences between the two types of a fermata initially seemed marginal, they led to surprisingly clear results. Although the movement of the hand during the duration of the fermata needs only slightly more energy in terms of muscle tension on the conductor's side, this action resulted in a much higher overall intensity of the evoked tone and a lower fluctuation of intensity, which combined improves the sound quality consistency of fermatas substantially.

An important implication of our findings is, that both the form of the trajectory and the hand posture elicit significant differences in sound quality, especially when the multiplication of the individual results (due to the high number of violinists and other string players in an orchestra) is taken into account. Concerning health related implications, as i.e. overstraining, future studies should measure the impact of different conducting gestures over a longer period of time. As for the conductor's risk of overstraining, by using convex conducting gestures with a neutral hand posture (instead of the other gestural types mentioned above) he can seemingly reduce his required muscle tension on a permanent basis and at the same time evoke a higher intensity of the sound of his ensemble.

V PRACTICAL APPLICATION

The presented research proves that there is an intuitive and consistent physiological reaction from different types and qualities of gestures of a conductor. Using this knowledge to map conducting gestures to both auditive and visual outputs in an intuitively understandable manner could tremendously enhance the artistic performance of the conductor and the efficiency of the rehearsals. Confirmed by numerous studies on multimodal perception, and, as seen in the stress-measurements and touch-sensor measurements, an incoherent mapping between gesture and demanded sound weakens the aimed effect, whereas consistent combinations of gesture, verbal instruction, sound and visuals would amplify and intensify the musical experience and strengthen artistic performances.

Visuals are already used to widen the effect of the perceived musical interpretation. Although mostly used in popular music, the classical scene also increasingly includes visuals to expand the impact of a performance. Despite many endeavors to develop ground-breaking new concepts by gesturally mapping singers[133] and musicians (see chapter II – 3c) and hence visually and auditively enhancing performances, the mapping of conducting gestures has proved to be difficult due to a lack of knowledge about the underlying mechanisms.

The presented findings of this thesis can be used as a foundation to build a framework for real-time mapping of conducting gestures in concerts, in order to either provide additional sound-effects or to add visuals as part of the genuine, real-time gestural language, instead of manually and separately controlling these effects using the score. Another advantage of such intentional mapping of an individual gestural interpretation is the possibility of adapting potential changes in interpretation to the added effects – in real-time.

[133] Torpey 2009, p. 93-118

Thus, general synchronicity of live performance and additional sounds/visuals could be substantially enhanced using this improved mapping procedure.

We propose a framework which incorporates the findings of the presented studies into algorithms in order to enable a real-time mapping of the interpretational characteristics embedded in intuitively understandable gestures (see figure 77).

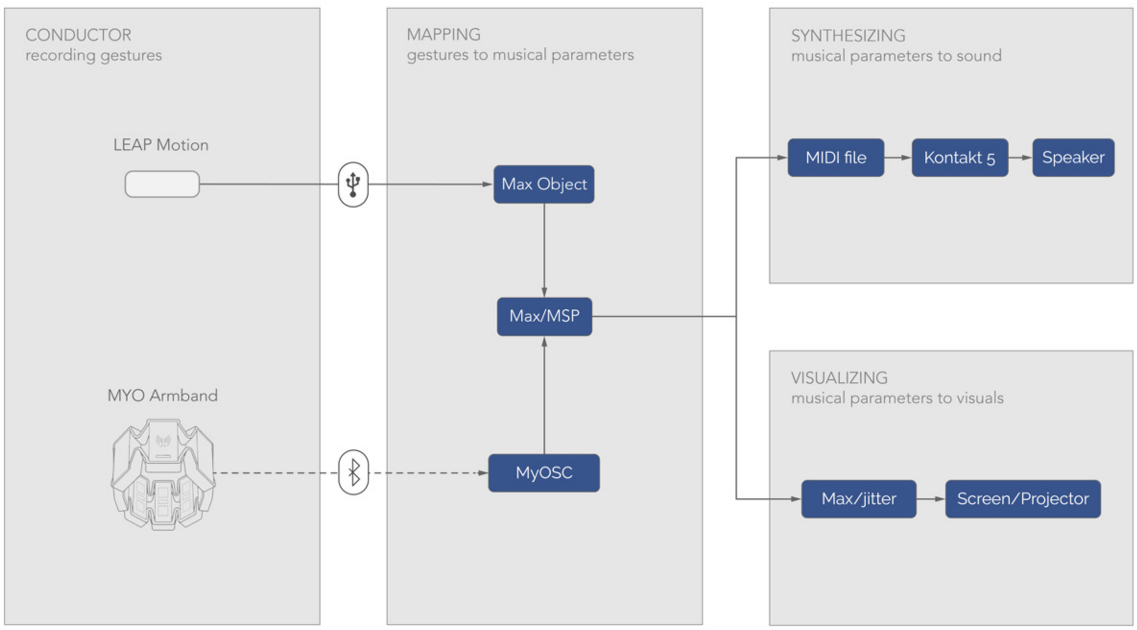

Fig. 77 System diagram showing component technologies and dataflow.

Using a *Leap Motion* sensor and a *MYO* armband, the framework can be deployed in live performance settings without disturbing either the conductor, the musicians or the audience. By means of the *Leap Motion* sensor we can detect the lower turning points as well as the form and size of the conducting gestures on the y- and x-axis in order to calculate tempo, dynamics and articulation. The *MYO* armband provides data for muscle tension, hand rotation, acceleration and gesture-detection, such as fist or spread fingers, mapped as various parameters of sound quality. These calculations are executed within *Max/MSP* and then send to e.g. *Processing*[134] or *KONTAKT 5* to be transformed into visuals

[134] Processing developers page (n.d.), accessed 03/31/2016

and music respectively. In order to take different conductor's individual gestures into account – especially different sizes of gestures – a calibration prior to the performance is necessary. Due to its modularity, this framework can easily be extended in accordance with future research in the field of conducting.

For reasons of economy and human resources, most conducting students have very limited access to working with real orchestras. Having to learn a virtuosic musical craft without a regular practice time with the instrument has proven to be problematic. Apart from the expressive-performative use, our framework could also be used to develop a supportive tool for conducting students. Such an application could include the deliberate analytical planning of a specific interpretation and afterwards, by analyzing the recorded gestures, it could both create a simulated orchestral sound and give feedback about the extent to which the planned interpretation overlaps with the actual result. Altogether, this would raise the awareness of the different musical parameters making up a convincing personal interpretation, improve conducting students' skills in planning this, and help training their motor skills and technical abilities before confronting a real orchestra.

The acquired results can also be applied within in the field of new musical instruments. With currently affordable consumer electronics for gesture recognition, such as the *Microsoft Kinect* or *Leap Motion*, many new gestural instruments are being developed (see chapter II – 3d.). Better knowledge about intuitively understandable gestures and their effect on the evoked sound quality could be of great value for developers of new gestural instruments to create mappings for a natural playing experience. Furthermore, compared with more or less arbitrary mappings, the consistency between gesture and evoked sound would create a more powerful performance not only for the performers themselves, but also for the audience, for whom a new option of recognizing haptic-motoric movement qualities and merging them with the resulting sound will intensify the overall artistic experience significantly.

VI CONCLUSION, IMPACT & FUTURE WORK

In this thesis, we explored fundamental principles of the communication between conductor and musician. In particular, we investigated potential influences of different types and qualities of conducting gestures on the sounding result and the musician's physiology.

Initially we presented the history and role of the conductor and reviewed relevant research on conducting and in related fields. In the main part, we introduced two studies exploring the physiological impact and the sounding result of different conducting gestures. Our findings show that there are consistent reactions to different types of trajectories and hand postures, indicating that it does indeed matter musically how conducting gestures are formed and executed. However, our findings do not aim to define any of the investigated types of gestures as being right or wrong. But it turns out that since every gesture has a unique sounding consequence, certain gesture types are more capable – more economical and effective – of reaching predefined musical/interpretational goals than others. Furthermore, with this thesis we can prove that a mismatch between the shown conducting gesture and the concurrent verbal demand for a specific sound envelope shape has a negative impact on both the musician's stress-level and the resulting sound itself. Thus, the key to a healthy conducting and rehearsing environment seems to be a consistency of the conductor's imaginative musical goal, his shown gesture, and the verbal demand.

Finally we presented possible applications of the findings and proposed a new framework, using the conductor's gestures as enhancement of musical performance, both auditory and visual. Additionally, we offered concepts of using the acquired knowledge for tools for the education of conductors as well as for the development of gesturally operated musical instruments.

Impact and Future Work

Our research represents what seems to be the first scientific approach to the actual influence of conducting-gestures on the musician's physiology. It adds an important factor to the knowledge about occupational illness in a vulnerable group of professionals as well as contributes to a deeper understanding of how conducting gestures influence the sounding result. For future investigations, we intend to conduct further studies by recording long-term data of musicians and singers in real-life rehearsal situations also including measurements of muscle tension and a more detailed recording of breathing types and breath support (especially relevant for choral singers and members of the orchestra's wind section).

Performance

The presented findings and applications have important implications for expanding musical performance and its perception by the audience. First of all, a higher coherence in the communication between conductor and ensemble improves the overall quality of musical interpretations and performances. Moreover, real-time systems for the creation of coherent multimodal representations of musical interpretations release synergies that can lead to new levels of experience and perception.

Education

The findings of this thesis research widen our knowledge about the semantic elements of music, and on a practical level it opens up a possibility to develop conducting simulators and efficient training programs for higher musical education. This can decisively enhance the starting position of inexperienced conductors before they are confronted with real ensembles, thus saving huge human and economic costs of live orchestras and choirs functioning as guinea pigs (an ensemble consisting of 30 professional players or singers costs at least $1500 per hour). More transparency and a better communication of the values of classical music might also help this vulnerable and struggling art form to a better standing and a bigger and more qualified audience.

Health

Recent studies show, that one third of absences at work are due to mental stress and anxiety,[135] which in a chronic state is known to lead to serious somatic diseases, such as hypertension, coronary artery disease, heart attack, etc.[136] Hence, proving a direct influence of incoherent gesture-task combinations on the musicians' stress level – and taking it into practical account – could have a tremendous impact on the diagnosis, the treatment and – not least – the prevention of some occupational illnesses among professional musicians. Likewise, a change of rehearsal methods towards more coherence of verbally predetermined musical tasks, conducting gestures, and aimed interpretation could improve not only the daily working environment of the 193,300 professional musicians (in the U.S.), but also lead to a more joyful and healthy experience for innumerable amateur singers and musicians[137].

Apart from these more specific musical effects – and extremely important for daily life and inter-human communication – an improved and more detailed knowledge of conducting might also influence the overall awareness of, and sensitivity to, gestuality and the effect of our physical expression on others.

135 Hope 2013, accessed 04/01/2016

136 Boonnithi and Phongsuphap 2011, p. 85; National Institute of Mental Health: Fact Sheet on Stress (n.d.), accessed 04/01/2016

137 U.S. Bureau of Labor Statistics: Musicians and Singers 2015, accessed 04/01/2016

LIST OF FIGURES

All figures were created by the author unless otherwise noted.

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