FACIAL HACKING: THE TWISTED LOGIC OF ELECTRO-FACIAL CHOREOGRAPHY

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Thesis is accompanied by a DVD with the same title.

Pre-face

“I NEVER FORGET a face, but in your case I’ll be glad to make an exception.”
Groucho Marx

Vivid memories remain from my first encounter with live electricity and since then I have become addicted to anything electric. This first physical contact was a mighty blow from the mains while probing around in a found record player. A trembling sensation took over my arm and hand and left a numb feeling. It was simultaneously painful and intriguing.

It was in the early seventies, at a time when mass consumption left the streets littered with obsolete electric devices: old vacuum tube radio and television sets, record players, hair dryers. As a kid I was fascinated by all this junk and found whole worlds to discover in these mysterious electric machines we were all so familiar with. Often devices were dumped just because a fuse was blown or had a faulty plug: “How stupid!” I thought. Built from electric parts taken from old radios, an intercom system was created, so I could talk to my neighboring friend over a wire tagged to the outside of the house, a system which was later extended over the garden to another friend. Soon we found this was cumbersome and could be done wirelessly by means of an awkward little device known as the *Jostykit*. Two transistors, a few resistors, capacitors and a battery was all that was needed to instantly turn oneself into an outlaw. It engaged me in the illegal activity called pirate radio. It remains a mystery to me until this day why anyone can claim ownership of the superfluid we call the ether: “How stupid!” I thought.

The quest for better transmitters, receivers and antennas had begun. Even though I became a prolific and well known supplier of home-made radio and television transmitters for the booming pirate radio and television scene in the Netherlands, the invisible mysterious force of electricity of which the wireless is part of remained a fascination.

At school it was fun testing the physics teacher’s knowledge about electricity by sticking a nail into the mains while holding it in one’s bare hand. To many of my fellow pupils this was shocking in a different way, the shock of negation of their presumptions. The shorted power plug was found to be a powerful weapon, it gave power to control, for example to blow the fuses on a ‘hated’[1] disco party.

Besides the knowledge to work *with* electricity, I never gained a full understanding *of* electricity as a natural phenomenon. To me electricity remains a mysterious force. It is, for example, surprising that with electricity itself we have so much control over electricity. The computer to me is the ultimate electricity manipulator, a box full of switches that allows electricity to be piped in any way imaginable.

It was however the human body in its capacity to detect electrical phenomena that triggered the discovery of electricity from ancient times onwards. The human body’s nervous system was found to be vulnerable to the application of electricity from the outside, triggering muscles into motion. In hacking terminology it is said that an exploit was found that allowed external control over the human muscular system effectively bypassing the brain’s privileged function. Hackers refer to the process of taking over full control of something as it has been *pwned*.[2]

In this thesis it is the human body and specifically the muscular system of the face that is subjected to a high level of hacking. While the human body was the trigger for the discovery of electricity, controlled electricity now triggers a new exploration of the body itself.

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[1] To emphasize the rivalry between two opposed youth cultures, the discos and the punks.

[2] A portmanteau of pawn (grab) and owned.

À mémoire de Guillaume Benjamin Armand Duchenne de Boulogne

Abstract

This research addresses the development of a computational facial language that enables systematic exploration of the external controlled human face with the aim to identify fundamental electro-facial choreographic patterns.

Rewiring the human face to an external digital control system, has sparked a radical new way of thinking about the human facial display. Radical, as facial movement is now rooted in digital instead of neural computation. The human face has become an extension of a digital control system inheriting its characteristics: i.e. temporal accuracy, consistency of execution and high programmability.

How do we conceptualize the thinking about the human face as a digital computational display device? What are the implications of the “regime change” from neural to digital?

The research addresses these issues within the contextual framework where it also originated, in the practice of hacking. It uses the results oriented methods and strategies of hacking to analyze, explore and contextualize the human facial display as a site for digital computational expression.

The contributions of this work include the following.

1) External facial control transgresses the neural performance limitations and enables us to think about facial movement from a digital computational choreographic paradigm.
2) A facial language, the *Language of Facial E-motion*, that allows systematic computational exploration of possible facial movement patterns. *Choreologic probing* of dynamic face space has brought about unseen facial movement patterns and has uncovered a latent expressive potential of the facial hardware.
3) An *Electro-Facial Choreographic Nomenclature* that describes the typical e-facial movement patterns in a binomial scheme that form the fundamental building blocks of electro-facial choreography.
4) External facial control has emancipated the human face from subjugation by the neural brain. Because the human face can be programmed at will, it can move freely, consistently and unencumbered; it metaphorically has attained *Freedom of Facial Expression*.

5) External facial control allows any external computational process to have unrestricted access to a possibly remote facial display. Consequently, the human facial display is made communist and has attained a *Democratization of Facial Access* on the hardware level.

6) On the meta level, the human face has found new uses, alienated from its original purpose of displaying the emotions, which is expressed by the German word "*Zweckentfremdung*."

7) Facial hacking, as presented in this thesis, can be of value to the discussion about cross- or interdisciplinary artistic research as being clearly positioned in-between disciplines.

8) A facial control system that allows safe and concurrent facial muscle control by means of a multiplexed mono-polar muscle stimulus scheme.

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Chapter 1

1.Introduction and Motivation

"It's about the differences between neural and digital computation and this makes all the difference." John von Neumann (1958) [3]

About thirteen years ago, out of a practical artistic need, I innovated electric facial muscle stimulation into something that turned out to be unique. The next decade was filled with performances around the world employing my electrified face as a new medium of sorts. Whilst hacking about with the face to create new performance pieces, the observation was made that through external computerized control of the facial muscles, the face can be made to perform in novel and often surprising ways. External controlled facial movement can be considerably more consistent and temporally precise than what the neural brain as the controlling agency is able to accomplish. But not much time was found to investigate the unique capabilities and characteristics of the human face in these artificial conditions at a fundamental level. Why the computer-controlled human face can behave differently than in its natural operation, and how we can take advantage of this inference, is the subject of this thesis.

In addition to the desire to address the issues outlined above, hacking about the computer-controlled human face or *e-face* for short, also urged the need for practical and conceptual tools to better manage and choreograph the facial movements. As an artist fiddling with wires and systems an approach to the research and thesis is chosen that is ultimately close to my art practice. Hacking is a practice based activity that is situated in between the disciplines of art, science and technology. It draws elements from these disciplines without being seated firmly within any of them, but still generates outcomes that contribute to these disciplines. Hacking is a peculiar activity that needs investigation to pinpoint its relevance to the exploration of the e-face as a new medium that will be named *electro-facial choreography* and as a method and context for this artistic research.

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[3] A summary of John von Neumann's "The Computer and the Brain" in the form of a quotation.

1.1.Transgressing the Neural Limits of the Human Face

The human face has long been considered the “reflection of the soul,” displaying the brain’s internal states to the outside world. Through my innovative art practice of wiring the facial muscles directly to an external digital computer system, it has been observed the human face can behave quite differently when controlled directly by a computer rather than securely operated by the neural brain. For instance it was found that facial behavior under external computational control, is more consistent and temporally accurate.

At first sight it might seem surprising that the human face under digital control can behave differently than when controlled by the neural brain. A closer look reveals that the human face is simply a display device, consisting of a number of actuators beneath the skin operated by an agency, pulling it into shapes to form the patterns we call facial expressions. The Swedish anatomist Carl-Herman Hjortsjö emphasized the notion that the human face is an orchestrated instrument: “The facial soft parts are, as a matter of fact, the instrument that varies from person to person and upon which the mimic musculature plays a melody very similar for one and the same condition.” (Hjortsjö 1969, p.11)

The controlling agency determines to a great extent, within the limits of the capabilities of the facial hardware, what melody can be played or how the human facial display can behave. In my work the natural controlling agency has been replaced by an external digital computer that mimics what the brain via the nerves would do to take control over the facial musculature. It does this by means of a specially-developed electronic interface which is used to generate small and precisely controlled stimulating electrical impulses that trigger the facial actuators or muscles into contraction. By this means the human facial display is fully controllable on all levels of movement through an external computer system. It has become with Hjortsjö an instrument for expression, but not an instrument of neural expression but an instrument of digital computational expression. The human facial display behaves as an extension of a system, neural or digital, inheriting, newly delimiting and displaying the system’s unique capabilities. The human face therefore is a visualizer of computation.

Neural systems further have a low level of programmability where it takes a considerable amount of training to learn new tricks. A prime example in this context is the classic Hindu

Kathakali[4] dance practiced in South-India where the face is very dynamically used to express various parts of the Mudras sign language. It takes years for a Kathakali dancer to reach a sufficient level of control over its face to be able to use the facial expressions that are part of this language. (Vijayakumar [no date])

In contrast digital systems can be programmed to a very high level where its output is completely deterministic. This notion has important implications for the research as it allows facial behavior to be programmed in a completely accurate fashion. External control further makes possible a synchronization to any, external or remote to the human body, event[5]. This opens up new possibilities for the human facial display which go beyond the capabilities of the neurally operated face and which will be discussed next.

1.2.The Emergence of Electro-Facial Choreography

Embedded within the human facial hardware, the muscles, bone and skin, lies an expressive potential that the brain, as observed in my work, doesn't fully utilize due to its neural origin. As such the neural brain is the limiting factor in exploring the face's potential expressiveness. External digital control however leverages the face's expressiveness into new territory, and it is the aim of research described within this thesis to explore and define this territory.

The face's expressive potential to a great extent is defined by the combinatorial possibilities of the facial muscle contractions delimited by the physical capabilities of the facial actuators, the muscles. The combinatorial space of possible facial contraction patterns, the so called *face space*, defines the face's potential expressive states. Most traditional facial scientific research, i.e. psychology and sociology, is working from the premise that the face is a communications medium that signals the brain's internal state, often called emotions, to the outside world and it does this by means of neurologically defined muscular contraction patterns. The term "facial movement" in this context is often used to describe these facial signals, which is mostly about facial displacement end states and not about the movement itself, and as such is a misnomer. In this thesis when discussing facial movement, it is meant as such, the face as a malleable surface that can move, generating movement patterns. By this

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[4] "Katha" means Story and "Kali" means Play.

[5] See Elsenaar's work "rEmote" from 1995, where the human face was directly wired to the internet, allowing remote visitors from around the globe to control his facial expressions. Or the Australian artist Stelarc's "Ping body" event of the same year.

notion it is possible to define a second combinatorial space, one based on facial movement patterns and sequences of these patterns. The research dubs this space *dynamic face space* in complement to the other space that more correctly should be named *static face space*.

Now that a dynamic facial space is identified, how do we go about exploring and defining this space? Neural exploration of face space as discussed has its limitations and its results are familiar to us as we practice and see it used every day. The background section of the thesis provides a brief historic survey of some of the more explicit examples of this explorative genre. Digital exploration of dynamic face space though has the advantage that any pattern can be programmed with ease and even large iterative or systematic methods can be deployed to map out the space.

It is crucial to realize that the face as an extension of a system, here a digital computational system, inherits the characteristics and capabilities of that system. For this reason the facial movement patterns that are generated by these means are inherently abstract and rooted in the logical operations and other intrinsic qualities of digital computation.

Due to the fundamental difference in neural versus digital facial control, the research postulates that digital computation allows for an unprecedented level of facial exploration and that this unveils new facial movement patterns. To find these patterns the research has developed conceptual and practical tools to aid in this exploration.

An explorative computational language is formulated, the *Language of Facial E-motion,*[6] that is based upon logical operations on muscles and muscle groups and is informed by the unique orientation of the muscles in the construct of the face.

By means of this language, facial movement can be logically defined and this has given rise to a new way of orchestrating the facial organ and exploring its merits in a completely systematic fashion. The language is deployed in a number of systematic experiments to find typical and fundamental movement patterns of the e-face that are subsequently identified and named in a choreographic nomenclature. The elements of the choreographic nomenclature form the building blocks of the emergent *Electro-Facial Choreography*.

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[6] Electronic movement of the face: facial e-motion.

The research further investigates the e-face as a digital kinetic medium and determines the fundamental properties of the facial actuators, such as muscle action, speed and digital resolution, as these are of value to establish the ultimate performance limits of the e-face.

To facilitate the research a new generation of an electronic facial muscle stimulus system is developed that increases comfort of the stimulating impulses, improves on safety issues and its practical usability.

To arrive at the stated goals a research method is developed that is close to my artistic practice and is related to the practice of hacking.

1.3.A Facial Hacking Approach

"It was not reason but a man-made instrument, the telescope, which actually changed the physical world view; it was not contemplation, observation, and speculation which led to the new knowledge, but the active stepping in of homo faber, of making and fabricating."
Hannah Arendt, The Human Condition (1958, p.274)

When people hear about hacking and hackers, their view might well be formed by negative publicity in the press. Hackers are those nasty people that break into computer systems to steal valuable information, like for instance credit card details or your identity. The online "New Hacker's Dictionary" by Eric S. Raymond (Raymond, 1996) calls this type of person not a hacker but a cracker. Hacking in its original meaning refers to the practice of creating furniture with an axe and since the nineteen fifties also to the practice of exploring the details of programmable systems to stretch their capabilities.[7] Universal Turing machines, machines that can function as any other machine, enabled this type of stretching activity due to their programmability. Mark Hinge in "Hacking: Art or Science" puts this in a more popular definition: "Making a system, program or piece of hardware do something that it was not designed to do." (Hinge 2005)

It is this explorative aspect of hacking that is one to one applicable to the practice of exploring and extending the capabilities of the human face that is under discussion here. The e-face is almost literally stretched beyond its 'intended' use. To clarify this point, hacking is a

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[7] At MIT, the Massachusetts Institute of Technology, the term 'hacker' was also used as slang for a person that dug deep into the innards of the first digital computer systems at their facility.

unique type of activity that warrants more investigation as it provides multiple vectors of interest in this context.

By its explorative results oriented nature, hacking uses methods and tactics that can either be very precise and methodical, or brutal and relentless, unprofessional even. It is a working process that Thomas Düllo (2005, p.29) in “Cultural Hacking” typifies as “serious play” and “playful seriousness” at the same time that Steven Levy (1984, p.23) in his famed book “Hackers” calls “wild pleasure.” The playfulness at the same time works as a real motor of innovation, Claus Pias (2001) in “Der Hacker” writes: “...the act of playing with technology explores its limitations and boundaries, that simultaneously will disappear and reappear again elsewhere.” [8] What Pias means is that the stretching activity brings down existing boundaries and by doing so imposes new ones, moving exploration and innovation forwards.

Traditionally hackers hack computer systems, which are universal machines in the Turing definition and therefore by *recoding* are able to become any other system. The same machine can become a radically different machine that in some cases can be the exact opposite of its original purpose. Because of this alienation of original purpose, “Zweckentfremdung” in German as Düllo calls it, hackers have grown to become sensitive to ambiguous and contradictory notions[9] embedded in systems and this has become part of their explorative tactics. Exploration is not just a way to get to know a system, but also to consciously introduce disorientations to direct the system in new directions.

Thomas Düllo argues this element of “Zweckentfremdung” or alienation of original purpose has parallels in the détournement tactic of the 1950s artist group the Situationist International, where on purpose the meaning of artworks or images is twist or bended to (radically) change its meaning. Society and culture are systems that can be hacked or *decoded*, *encoded* and *recoded* to change their directions and meanings, *cultural hacking* as Düllo designates this activity. Naturally hacking gained a political dimension that has found its own proponent by name of Richard Stallman and the Hacker Ethic. More on this in the Recoding chapter.

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[8] Translated from German.

[9] Much like artists.

The Hacking Method

Hacking as an activity combines different elements, it is an explorative practice that attempts to find out about how systems work (on any level) in order to change it. It does this by using any method that produces results, whether these are systematic methods or playful probes to just see what happens. Düllo: “Hacking produces experimental research methods for a precise and calculated intervention in the system, also when from point of the system these seem irregular or unprofessional. In reality such an intervention is more likely artistic. That is to say the hacker merges the (analytic-systematic) practice of the engineer and scientist with the (creative-playful) practice of the artist.” [10] (Düllo and Liebl 2005, p.29)

The research, a continuation of my ‘art’ practice, that resulted in the emergence of the medium of the e-face, has a striking resemblance to the qualities of the hacker to merge engineering, science and art. To be more precise, this type of practice draws elements from these three disciplines without being seated firmly within any of these particular disciplines because it often negates the well established principles and methods of these disciplines.

Stephen Wilson in “Information Arts” argues for an overlap of the disciplines of art, science and technology as an intersection. (Wilson 2002) It can also be argued a space in between these disciplines exist because methods and outcomes are too irregular and unprofessional to be viewed as part of these disciplines. Perhaps a nitpicking argument, but it underlines the discipline agnostic nature of this type of practice, where “facial hacking” is clearly situated within. It not just provides a clear context for the research / work, but also provides methods and strategies for further exploration of the e-face the research is aiming for.

The basic premise of hacking as a method is a loose way of shaping something to one’s liking. This can involve relentless hammering or precisely placed blows to put something into shape. Hacking is characterized by exploiting the unknown consequences of probing a system. In facial hacking this is exactly what happened, it turned out that controlling the face by a digital computer, applying algorithms to electrically stimulated facial muscles, the face proved to behave very differently than under neural control. The research sets out to exploit this previously unknown consequence even further.

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[10] Translated from German.

The research therefore aims to map out or define the new (dynamic) face space that has emerged. To find fundamental movement patterns that will define e-facial choreography, it needs methods for probing dynamic face space. The available tools are inherently computational and consequently dynamic face space can be explored by methodical or systematic means. A permutation or full enumeration of all possible movement patterns is a likely methodical candidate for systematic mapping of this space, but due to its infinite size problematic and clearly impractical. Other strategies are needed to narrow down dynamic face space to a space where clearly defined e-choreographic patterns might emerge.

This is where the precisely placed blows of the hacking method comes into play. The research does this by strategically placed probes in a narrowed down space that is delimited or informed by the localization of the muscles within the unique structure of the face itself. Within this topologically reduced space, systematic logical operations are then used to map out these sub spaces. *Choreologic probing* as a method combines systematic exploration with topological knowledge about the face.

In summary, this method comprises the *decoding* (analysis) and *encoding* (explorative probe building) stages in the hacker methodology. Its results are evaluated, categorized and contextualized (politicized) in the remaining *recoding* stage. These three distinct stages further informs and provides a clear structure to the thesis by sectioning the research into clearly defined de-, en- and recoding segments.

The positioning of the work in between disciplines as discussed, has ramifications for the research and consequently for the thesis. It draws elements from these disciplines, but as practice based, results oriented artistic research it does not attempt to be technically and scientifically correct. Yet, it works exactly along the lines where it originated: in facial hacking and consents to its political implications.

1.4.Problem Summary

The principal problem the research seeks to address is one of charting a space that is largely unknown. What does this space look like and how can it be explored to define its fundamental characteristics. How does a human face under computational control behave and how do we conceptualize the thinking about the human face as a computational display device? What are the implications of the “regime change” from neural to digital?

The research addresses these issues within the contextual framework where it also originated, in the practice of hacking. It uses the results oriented methods and strategies of hacking to analyze, explore and contextualize the facial display as a site for computational expression.

The thesis addresses its various facets in terms of an explorative facial framework or language, the *Language of Facial E-motion* and chronicles its design and ideas, which are rooted in the intrinsic qualities of digital computation itself.

It describes a computerized facial control system which allows precise and safe control over the facial muscles. Both the facial control system and language are deployed in a series of systematic experiments and demonstrations to explore facial movement patterns on a generative and systematic level. Typical facial e-motion patterns are then analyzed and named in an e-facial choreographic nomenclature, that form the fundaments of electro-facial choreography.

1.5.Organization

The thesis is organized in three distinct parts comprising the decoding, encoding, and recoding stages of the hacking method as outlined above. It is preceded by a background section containing a brief historic survey into external muscle control and methods of facial exploration. In addition, an evolutionary account of my work is provided in the establishment of the facial display as a computational expressive site.

The first part, the *decoding* stage, investigates the features of the human facial display such as appearance, structure, movement, and control mechanism. It surveys previous facial research such as the Facial Action Coding System and identifies the most important expressive muscles in relation to external control. Neural versus digital control over the facial muscles and the face’s expressive potential is discussed leading towards an explorative strategy in terms of a language.

The *encoding* stage that logically follows deals with computational facial exploration on two levels. First it chronicles the design of an efficient facial muscle stimulus system that enables computational facial control on a practical level. Second it describes the creation of a computational explorative facial framework in the form of a language. The Language of Facial E-motion is based upon a few layers of abstraction describing the lowest operational level of a single muscle action, up to theoretical logic operations on sets of muscles and higher level functions. The grouping of these sets of muscles are strategically chosen according to the arrangement of the muscles in the structure of the face (choreologic probing). Both computational tools, the facial muscle stimulator and the explorative facial language are then deployed in a number of systematic explorations to map out dynamic face space.

The concluding *recoding* stage concerns itself with the evaluation of the human facial display under computational control. It analyzes the outcome of the explorations to identify the fundamental movement patterns that have emerged through the computationally orchestrated muscles of the e-face. The typical computational movement patterns are then named in a nomenclature: the Electro-Facial Choreography.

The recoding section further concludes that the behavior of the digital controlled human facial display is intimately linked to the principles of computation, and its behavior as such can be regarded a reflection of a computational system, whether this is neural or digital. It discusses the implications of external and digital control of the human face in a broader context, formulating a democratization of facial access and a liberalization of facial expressiveness.

The *appendix* provides background information on the workings of muscle, issues related to external muscle stimulation, a summary of the facial action coding system, the electro-expressive muscles, experimental data tables and a section on health and safety issues about working with electricity and the human body.

Chapter 2

2.Background

2.1.External Muscle Control

"De viribus electricitatis in motu musculari."[11] Luigi Galvani (1791)

The human body in its capacity to experience phenomena, has played a crucial role in the discovery of electricity. As early as 46 A.D., Scribonius Largus, the physician of the Emperor Nero, reported in his medical treatise "De Compositione Medicamentorum" that he cured a freeman of Tiberius from headache by applying a live torpedo to his head. (Viktorov, 2002) The therapeutic effect of the shock provided by the electric eel and torpedo was well known throughout antiquity, (Rowbottom and Susskind 1984, p.35) but they had no idea it was directly related to a phenomenon that was called electricity in which a rubbed piece of amber was found to attract small particles. The eighteenth century showed a great interest in the electrical phenomenon and it was discovered sparks pulled from an electrified human body could heal paralysis. The Leyden jar with its high capacity to store electricity was found to produce powerful electrical shocks that could shiver the muscles of a subject to a considerable extent.

It was Jean Jallabert (1712-1768), professor of experimental philosophy and mathematics in Geneva who discovered human muscles could be triggered by the application of electricity. (Rowbottom and Susskind 1984, p.16) Jallabert can be characterized as the biological hacker who found the fundamental vulnerability of the human body's actuator system to be accessed externally and this has given rise to various exploits of the muscular system. However there was still some (surprising) confusion ahead about the true relation between electricity and muscles.

In the now famous frog leg experiment by Luigi Galvani, a prepared frog leg with a copper hook was hung on an iron gate and the leg was found to twitch when the wind blew it

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[11] On the Effect of Electricity on Muscular Motion.

against the balustrade.[12] He thought the shortcut of metal hook and gate to release the stored electricity embedded in the animal's muscle and this caused the contraction of the frog's muscles. After he published his findings[13] a fierce debate erupted with his contemporary Alessandro Volta (1745-1827), where Volta claimed the combination of the two different metals caused the convulsion and not the release of what Galvani had called 'animal electricity.' Although Galvani's frog leg observation directly lead to the invention of the first stable source of electricity, the Voltaic pile or electric battery, the whole idea of animal stored electricity was dismissed and replaced by the notion that animal muscle could be triggered into contraction by the application of electricity.

Now that the correct relationship between electricity and muscle contraction was established, different scientists started to explore its manipulative effects. An outstanding practitioner of this activity was the French neurologist Guillaume Benjamin Armand Duchenne (de Boulogne)[14] (1806-1875) who applied precisely calibrated electrical impulses to the muscles of the human face to study the relationship between the expression of the emotions and specific muscular contractions. He named the muscles accordingly: e.g. the muscle of joy, the muscle of sadness.

Duchenne as the first facial hacker built and refined his own electrical stimulus apparatuses. His work became the first example of refined external control over the muscles of a human person. The following century electric muscle stimulation grew into a field dominated by medicine and saw ever more developed methods of electrifying the human body, mostly for medical and therapeutic purposes. Electricity as a destructive force was also 'effectively' explored by means of the infamous electric chair.[15]

The arts in the twentieth century assimilated almost any emerging new technology and appropriated it for artistic purposes. Not so with electrical stimulation of the human body, not even the hippies in the sixties and seventies touched electricity for their mind expanding

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[12] At the same time Galvani's wife Lucia noted that at the instant of an electric spark from a friction machine operated across the room, a frog's leg would twist when its spinal cord was in contact with the steel scalpel hold by an assistant. (Becker, 1985)

[13] Galvani's frog leg finding became so popular that almost the complete population of frogs in Europe was wiped out. (Rowbottom and Susskind 1984)

[14] Duchenne had "de Boulogne," his place of birth, added to his name to distinguish him from Édouard Adolphe Duchesne (1894-1869), a well known society physician in Paris. Throughout literature Duchenne is used with and without this designation, even in his own publications.

[15] See Elsenaar, Scha discussion of the electric chair. (Elsenaar and Scha 2005)

efforts.[16] This changed when Australian artist Stelarc detached *itself* from the flesh hooks and attached itself to ever more complex electrical systems. Body signals were detected and amplified in performance/installation pieces that explored the human body as a technological object to be manipulated at will. In some of his work Stelarc started to use medical muscle stimulus devices, or TENS units (Transcutaneous Electrical Nerve Stimulation), to investigate technological driven *involuntary movements* of the human body. Muscle control with TENS devices is rather crude, but in this case conceptually sufficient.

2.2. Evolution of my Artistic Work

In the early nineties I started to contribute to the evolution of external muscle control when I made an artistic decision to enhance the experience of my body by technological means. It was a direct response to the then fashionable idea of the “body in ruins” that did the rounds in the emerging new media arts scene. Instigated by the emerging global communications medium of the internet, the idea was put forward that the body would become a redundant shell as the mind could travel around the globe, doing away with the need to physically meet.

At the time this was, in my opinion, an objectionable absurd idea that needed a counter measure. I decided to increase awareness of the body by making my body intensely experienceable. In a performance piece, an interface was created between the audience and my body by casting my personal zone into the surrounding space by means of a small portable Doppler radar [17] system. Whenever a member of the audience stepped into my extended personal zone, their movement and proximity were directly translated (amplified) into increasingly strong and jerky movements of my own body, which were brought about by the electrical stimulation of my muscles. A one to one, intimate and wireless link was established between the movement of the audience and the movement of the artist’s body.

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[16] Although rumors claim that in the former Soviet Union due to the lack of drugs, for kicks people chain shocked themselves of the mains.

[17] Technically this device is known as a Gunnplexer.

Figure 2.1: “Body Convention” Elsenaar, 1993

The Doppler radar signals were amplified and directly fed into the body as electric stimulating impulses setting the muscles of the face and shoulders into increasingly powerful convulsions. The resultant expression of pain in the face and nonchalance by the shrugging of the shoulders painted a dualistic image in the mind of the observer.

The dedicated electronic system that I developed for this purpose consisted of a simple square wave pulse generator, a few transistors and an amplifier for the relatively weak Doppler signals. This effectively constructed a continuous spatial movement to muscular movement converter, where proximity is in direct proportion to the intensity of the electrical shocks. Although this setup was effective technically and in its affect on the audience, the level of control over the muscles of the face was extremely limited. The two electrodes attached to the face crudely stimulated the whole paired facial nerve trunk[18] contracting all facial muscles at once.

“Body Convention” as the piece was called, kicked off a series of work spanning more than a decade. Each time a new piece was conceived in an iterative fashion with the emerging possibilities and needs of the conception, the muscle stimulating electronics became more refined. (Figure 2.1)

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[18] Nervus facialis (seventh cranial nerve)

Having found the facial muscles could be controlled externally, the next logical step was to gain more refined control over the facial muscles. Studying the electric signals needed for the stimulation of muscles, it appeared short rectangular wave pulses of about 1 ms and a (repetition) frequency of about 20 ms (50 Hz) are particularly beneficial[19] for sustained contraction of the muscles. (Gillert 1977, p.15) My intuition at that point was that the remarkable wide space in between the repeated pulses[20] allowed to fit in other pulses. In other words, many muscles could be sequentially stimulated at seemingly the same time in a technical scheme known as multiplexing.[21] This early and intuitive decision turned out to work very well in a first computerized digital system that was developed. The setup with a single large electrode, the anode, placed at a central location on the chest with multiple small electrodes, the cathodes, placed on the so called motor points[22] of the subjected muscles was in part derived from text and images from Otto Gillert's book on electrotherapy.

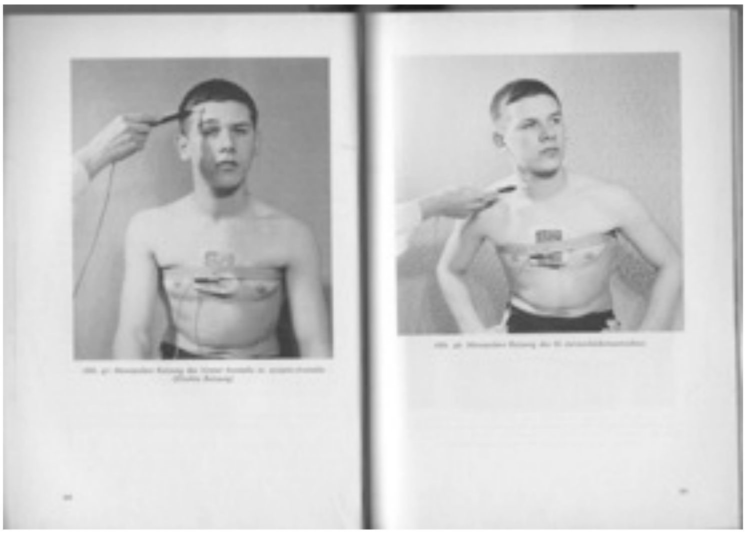

Figure 2.2: Inspiring images from Gillert's book (1977) on electrotherapy. (subject unnamed)

Around 1985 I found this little practice based book in secondhand bookstore "Wonderbook" [23] in Amsterdam. It triggered my interest in the relationship between the human body and electricity and has been a great source of inspiration. (Figure 2.2)

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[19] As a side note, the choice of 50 or 60 Hz for the mains is unfortunate as inadvertent contact with electricity can cause holding muscle cramp and cardiac arrest that has resulted in many (unnecessary) deaths.

[20] The stimulating rectangular wave pulse has a notable high to low ratio of about 1:20.

[21] Multiplexing is a technical process where multiple signals or data streams are combined into one, so it can be transported over a single channel medium, for example in telecommunications.

[22] This is the point where the impulses carrying nerve enters the muscle.

[23] A bookstore of a friend specialized in old science books, 'boy wonder' books and so on.

The first multiplexed muscle stimulus system which I developed [24] had eight output channels allowing simultaneous control over eight muscles or muscle groups. By varying the amplitude and width of the stimulating impulses in software,[25] facial muscles could be controlled to a high level of detail in the whole range from fully contracted to fully relaxed. Unfortunately the designed flexibility in the system had negative consequences. In early body resonance experiments, a low frequency, wide, high amplitude stimulus pulse was administered to the deltoid muscle and likely the brachial plexus servicing the left upper limb. The shoulder could be made to shake vigorously and I was happy with the result of the experiment and envisioned new dramatic performance pieces. Until the next morning when I found the two outermost fingers on my left hand had become numb. After consulting my general practitioner and a physiotherapist I ended up in hospital, where the neurologist on duty set out to test the efferent nerves of my left arm. An electrical impulse is administered to the nerves in the upper arm and subsequently a resultant nerve impulse is measured in the lower arm and hand. The impulses arriving in my hand were very weak, so the conclusion was that along the way some nerve was damaged (or “zapped”). In relative fortune damaged nerves regenerate themselves and grow new dendrites that (hopefully) connect again to the right tissue,[26] so normal function is restored. Another measurement revealed high electric nervous activity as a sign of restoration. The neurologist claimed regeneration of the nerve, rebuild of declined muscular tissue [27] in the hand and full restoration of hand function would take a couple of months. In practice it has taken at least two years for my left hand resumed normal operation and up to today the feeling in the hand is different from the other.

The intriguing relationship of electricity and the human body warranted more study. The history of electric muscle stimulation revealed exceptional work by the aforementioned 19th Century French neurologist Duchenne who by localized electrical stimulation investigated the relation between the emotions and specific muscular contractions in the face.

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[24] Five wired up ‘extra’s’ wearing portable muscle stimulus devices, were intermingled unobtrusively with a festival audience and when talked to always showed the same automated physical response. Title: “HumaTiCks of the Present.”

[25] This was done in FORTH, a stack based programming language designed by Charles H. Moore in the early seventies. In my view this computer language is one level up in abstraction from programming with mnemonics, a symbolic representation of machine or assembly language.

[26] There are known cases for instance after Bell’s palsy, where damaged nerves in the face in the process of regeneration grow dendrites into the wrong muscle. For this reason emotions can be ‘miswired,’ triggering the wrong facial signals, a condition called synkinesis.

[27] ‘Denerved’ or inactive muscle tissue starts to decline within 24 hours.

Inspired by Duchenne's work I designed a performance/lecture entitled: "Huge Harry: Towards a Digital Computer with a Human Face." [28] (Figure 2.3) This piece which became my most known piece, required full control over the main expressive features of the face. For this reason an extra eight stimulus channels were needed and fitted onto the controlling digital computer system. This effectively established the human facial display as a site for digital computational expression.

Figure 2.3: Huge Harry: "Towards a Digital Computer with a Human Face." Elsenaar and Scha, 1994 Photo: Josephine Jasperse

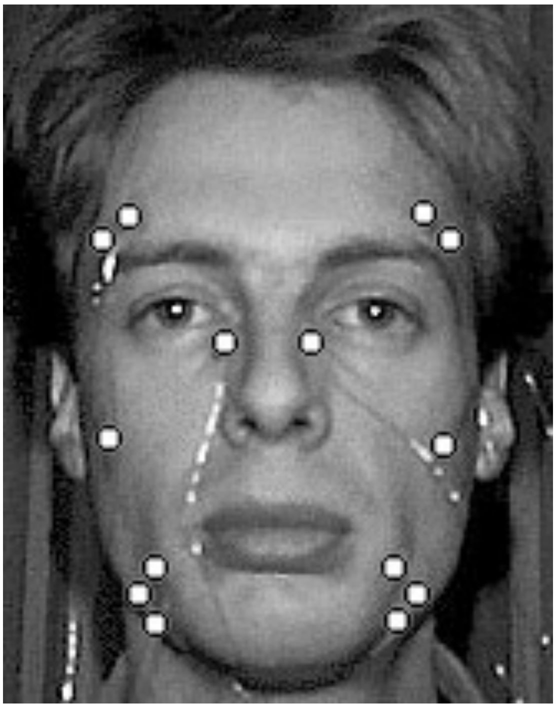

Figure 2.4: "rEmote" Elsenaar, 1995 (Internet performance)

It was surprising the face could simultaneously be controlled externally to a high level of detail sporting a system with just one central electrode and a number of electrodes located at specific muscle motor point locations without much interference from the other stimulating impulses.[29]

The face was also offered as a remote controlled explorative interactive 'canvas' in a piece from 1995 called "rEmote" where my face was directly hooked up to the internet.

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[28] "Huge Harry" is one of the standard voices of the classic DECtalk voice synthesis machine and alter ego of Dutch computer linguist and artist Remko Scha.

[29] The high resistance of the skin effectively isolates the electrode electrically on the skin, it 'forces' the immediate flow of the electrical currents to deeper tissue away from the superficially embedded nerves.

While I was sitting in front of a camera in Groningen the Netherlands, people thousands of miles away at the McLuhan Institute in Toronto, Canada clicked on a web enabled map of my face as a compositional tool to distort my live facial features to their liking.[30] (Figure 2.4) Here the internet infrastructure acted as an extended nervous system replacement. Physical remote control or facial access was not only pushed to the limits, it also exemplified the facial display as accessible by external to the human body computational processes.

Until this point, the facial display could be controlled externally to a high level of detail, but full dynamic exploration had to wait till "Arthur & The Solenoids," an algorithmic facial dance piece developed with artist and computer linguist Remko Scha. The piece demanded detailed generation of facial stimulation patterns in the temporal domain, something very suited for musical software like Max/MSP. [31] For this purpose a MIDI [32] interface was fitted onto the controlling electronics hardware, which allowed full dynamic control over the human facial display. By this means the face had become a musical or visual instrument of sorts.

Through persistent facial hacking, I have evolved the human facial display from a neural expressive medium into a new digital computational expressive medium. The facial display has become, with the aforementioned Swedish anatomist Carl-Herman Hjortsjö, an instrument for expression where the facial musculature not (just) plays a neural but also a digital computational melody.

For an overview of this artistic development, I refer to the schematic timeline provided in Appendix A. For reasons of comprehensiveness, it includes intermediary work not discussed and work that came out of this research.

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[30] An ISDN video conference link provided live feedback.

[31] A time based visual musical programming language originally conceived of by Miller Puckette.

[32] Acronym for Musical Instrument Digital Interface, the common communications protocol and interface for musical instruments.

2.3.A Brief Survey of Facial Exploration

"I feel certain that the largest part of all photographs ever taken or ever to be taken, is, and will continue to be, portraits. This is not only true, it is also necessary. We are not solitary mammals like the fox or the tiger; we are genetically social, like the elephant, the whale and the ape. What is most profoundly felt between us, even if hidden, will reappear in our own portraits of one another." Ben Maddow (1977, p.16)

The previous section demonstrated how the human facial display, through progressive hacking, has evolved into a site for digital computational expression that can be explored accordingly. Before we discuss computational facial exploration in detail in the next chapters, we zoom out a little first and briefly investigate how the human facial display in history has been explored as an expressive medium.

Above statement by Ben Maddow “Faces,” a book on the history of the portrait in photography can be extended to other media before the advent of photography for instance to painting and sculpture. It points to the importance humans attribute to their facial appearance, whether this is formal portraiture in the seventeenth century or playful explorations in modern art history.

A given in portraiture is that the face is mostly displayed as the center piece of the composition, grabbing attention. Facial expressions can be absent as in formal portraiture, painting the picture in the viewers mind that everything is under control, or cartoon-like exaggerations as in Franz Xaver Messerschmidt’s sculptures or Francis Bacon’s paintings.

Everything in between and beyond these extremes can be seen as explorations of the facial expressive capabilities. The following brief survey focusses on the different methods of facial exploration in order to validate the research’s aims and method.

2.3.1.Methods of Facial Exploration

An initial historic survey of the vast amount of facial depictions identified a number of facial distortion methods that can be roughly categorized as follows. The physically constrained, naturally operated face as in photography and the nonphysically constrained human face as in painting and sculpture. By this is meant a face that is neurally operated by the brain, operating within its natural physical constraints and facial depictions as completely unrestricted.

As will be seen in the sections which follow, we can further subcategorize the physically constrained into methods to distort the facial appearance with mechanical aids. Here the facial surface is not distorted by a controlling brain, but by externally applied forces. The non-depicted physical category can even be explored on the face's physical self, i.e. destructive irreversible deformation.

The ability to explore the face in a systematic manner is the last, but for the research most important category to define. Let us examine these facial exploration methods in more detail by looking at some compelling examples for each category.

Figure 2.5: Laocoön and his sons ca. 200 BC. Emotion related facial expressions. Note that on copies Duchenne 'corrected' the curves and furrows on the forehead of the Laocoön after his laws of facial expression.

Physically Constrained and Naturally Operated

Far back in time, only depictions of the human head in sculpture, mosaics and paintings remain as a record of facial distortion. Many of these portraits were made for formal purposes, showing a notable in a favorable position with often a neutral, that is — everything is under control — facial expression. Although the display of a blank face shows an emotional state, others show emotion related expressions like suffering and fear, for example in figures from Roman or Greek mythology. (Figure 2.5)

From the ancient historic record of art and science, I have not found clear examples of facial expressions that go beyond the expression of the emotions. In the seventeenth century exceptions start to appear through painting and later sculpture.

Figure 2.6: “Study of a Young Woman”, circa 1665-67, Johannes Vermeer (1632-1675)

Figure 2.7: “A Hanged Man”, after 1770, Franz Xaver MesserSchmidt, Although the hemp rope suggest a hanging, the moistened rope was part of Mesmer’s healing methods to conduct the magnetic fluid.

The *Tronie*, a now defunct Dutch word, refers to head, face or expression and is used to indicate an informal painting style practiced by among others Rembrandt van Rijn, Johannes Vermeer and Jan Lievens. They chose to paint the tronies of people because of an exceptional expression, odd character or anything else worth practicing on. Because the tronies were made for study purposes, not official portraiture, it could explore the range of human physiognomy[33] and facial expression and for this reason were sold on the open market.

The exploration of facial expression was taken a step further by the Austrian sculptor Franz Xaver Messerschmidt (1736-1783), a contemporary of Franz Anton Mesmer[34] and Johann Kaspar Lavater that became known for his study of physiognomy.

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[33] The study of facial features as indicative of character or ethnic origin. (Oxford Dictionary)

[34] Messerschmidt and Mesmer lived in the same house. Mesmer’s (in)famous healing practices were of great influence to Messerschmidt.

Messerschmidt a gifted sculptor renown for his high quality portraiture and *rapid prototyping* of human heads,[35] had a personal interest in the depiction of characters or the expression of insanity. (Krapf 2002) He himself suffered from a not defined and disputable psychological disorder which might have triggered his interest in the topic.

The sculpted portraits he produced, named “character heads” after his own designation, in the history of art, are truly unique in its depiction of facial expression and quality of sculpture. It is suggested that Messerschmidt was not just interested in the portraiture of the head’s inside on the outside, but was experimenting with a “systematics of heads” to rationally solve the problems of the “situation humaine.” (Krapf 2002, p.16) The character heads show the complex expressions of the “tormented human physique and psyche,” most likely the patients of Mesmer undergoing “animal magnetism” treatments. (Krapf 2002, p.9)

Siegmar Holsten in the catalog for an exhibition in Hamburg in 1978 however argues that Messerschmidt’s character heads are not products of mental derangement, but a demonstration of “an almost scientific, systematic interest in exploring every last possibility presented by the facial muscles.” (Krapf 2002, p.67) An implausible argument as none of the character heads show for instance the face’s ability to display asymmetrical expressions.

The headstrong Messerschmidt showed his genuine interest in the expression of the human psyche when he reportedly aimed a pistol at a “Jewish trader” entering his house, just to observe the fear of death in his face. (Krapf 2002, p.160)

Messerschmidt’s out of commission portraiture work can be likened to the Austrian sculptural counterpart of the Dutch tronie, showcasing the naturally generated, physically delimited, and often exaggerated, cartoon-like emotional facial expressions.

Throughout history however people undoubtedly have been pulling faces at each other, exploring the malleability of their faces beyond the display of the emotions, but we had to wait till the last century for their appearance in the annals of history.

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[35] Messerschmidt was able to “model a face of the highest quality in clay within the space of just two hours.” (Krapf 2002, p.25)

Figure 2.8: Gordon Mattinson has won the World Gurning Championship ten times. Note the uncharacteristic tactic of this gurner to leave his teeth in.

Figure 2.9: Eric Tate a.k.a. Facethoven, voluntarily animating his facial expressions to the music of Beethoven: a natural face-ist.

This type of *voluntary facial exploration* has been pushed towards the extreme in a popular English pastime; the gurning contest. An outstanding example of this highly developed and popular art form is Gordon Mattinson, who has won the World Gurning Championship no less than ten times. Eric Tate a.k.a. Facethoven, another Brit, has taken voluntary facial distortion to another level. As a true facial contortionist or natural face-ist, Eric Tate trained himself to pull faces synchronous to music of Beethoven, a kind of animated gurning or mime.[36] It is noteworthy that Eric Tate explores facial movement patterns and not just static expressions as in gurning. Both these examples show the most developed instance of the naturally delimited and operated facial explorations; e.g. jaw movements, lip curling and asymmetricals.

Physically Constrained with Mechanical Aids

Deforming the facial surface beyond what is possible with the neurally operated facial actuators but within the face's physical constraints, requires forces administered from the outside. A natural follow up to pulling faces voluntarily is to aid the deformation of the face with the hands. The facial features can be stretched and pulled beyond the neural limitations.

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[36] http://www.youtube.com/watch?v=MHSt1U_-pbA

An early example of *manual facial exploration* is Bayern comedian Karl Valentin who pushed and pulled his face into contortions.

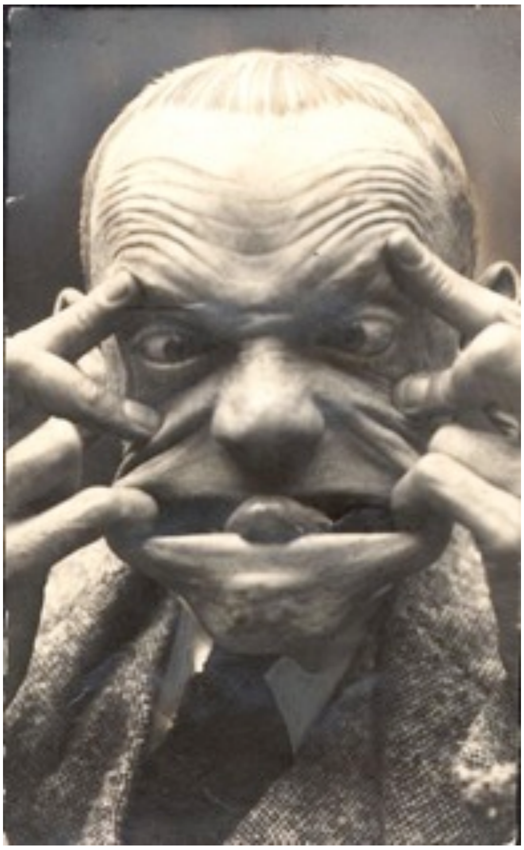

Figure 2.10: Karl Valentin (around 1930) An example of manual facial exploration.

More recently artist Bruce Nauman released a follow up to his facial explorations series, his 1970s “Hologram studies.” “Cockeye Lips” is a well executed example of an extreme manual asymmetric, pushing facial features into utmost physical constraints.

The ultimate manual facial contortionist though is Garry Turner from Caistor, Lincolnshire in England. Turner has a rare medical condition called Ehlers-Danlos syndrome (EDS) also known as “Cutis hyperelastica,” a disorder of the connective tissues affecting the skin, ligaments and internal organs. It is caused by a defect in the synthesis of collagen, a protein that strengthens the skin, resulting in hypermobility of the joints and a loosening of the skin. “Rubber Band Man” or “Elastic woman” is a popular designation for people having this condition.

EDS allows the face to be stretched and explored beyond the normal physical constraints. This utmost malleable condition and explorability of the face is more akin to Kai's Power GOO facial image manipulation software of the early 1990s than the normal physical face.[37]

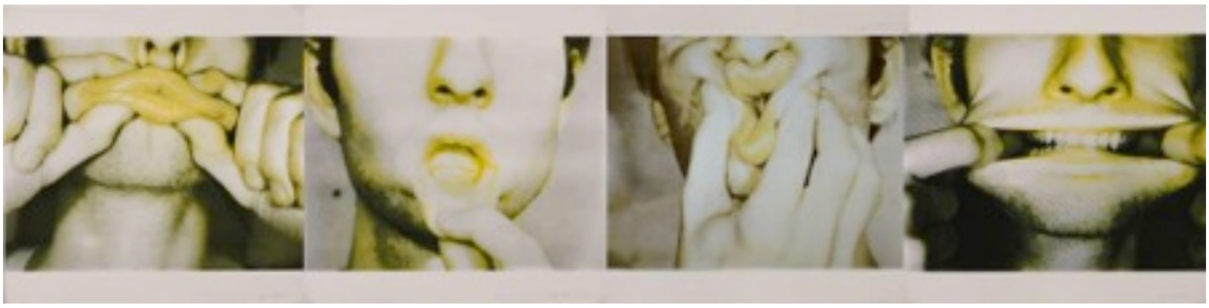
Figure 2.11: "Hologram studies", Bruce Nauman 1970s


Figure 2.12: "Cockeye Lips (Infrared Outtakes Series)", Bruce Nauman 2006


Figure 2.13: "Rubber Band Man", Garry Turner, UK, demoing his Ehlers-Danlos syndrome originated rubbery skin condition.

Another level of manipulations of the facial surface is made possible by the use of mechanical aids in support of the hands, for instance glass plates (Mendieta) or a (transparent) facial harness (Hartley[38]). Pulling forces applied to the facial surface can be directed with more precision by using sticky tape (Gordon) or glued on hooks and wire (LucyandBart). (Figure 2.14 - 2.17)

Gravitational forces and airflow are yet another method to distort the facial surface within its physical limits, albeit a non contact one. (Paolozzi)

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[37] A computer program intended to poke fun at the portrait by allowing to distort portraits in a fluid fashion.

[38] Artist Paddy Hartley is the initiator of the aforementioned Project Facade.

Figure 2.14: “Glass on Body”, Ana Mendieta 1972

Figure 2.15: “Face Corset”, Paddy Hartley 2003

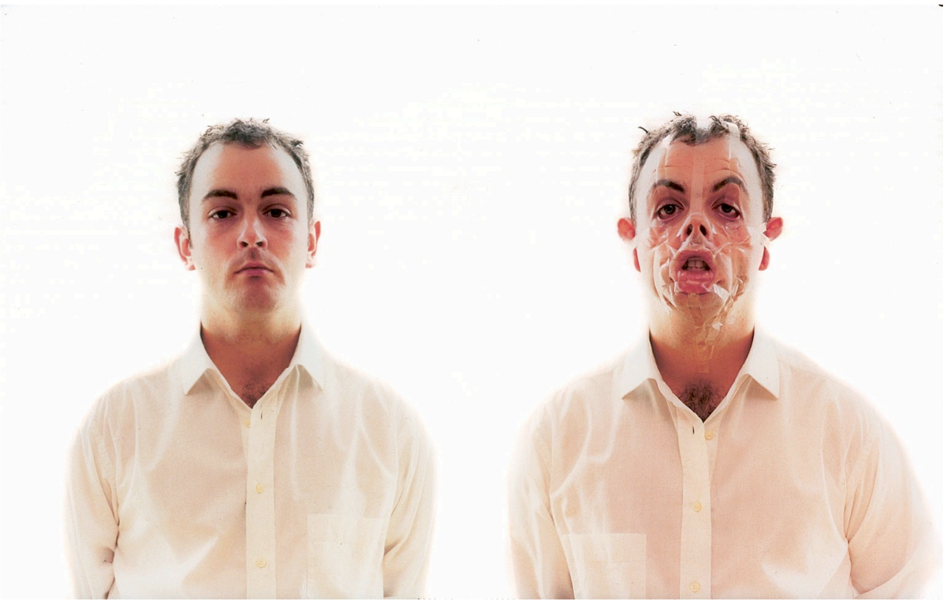

Figure 2.16: “Monster”, Douglas Gordon, 1996

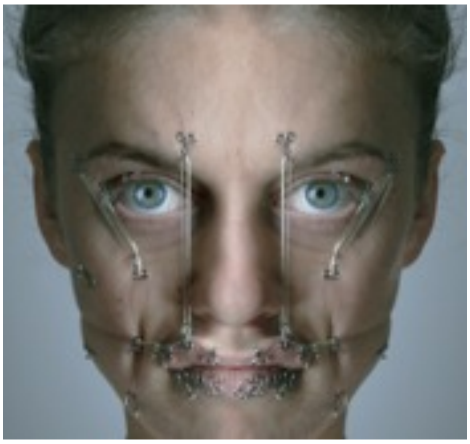

Figure 2.17: “Hook and Eye” LucyandBart (Lucy McRae and Bart Hess), 2007

Figure 2.18: “Windtunnel Test” 1950, presented by Eduardo Paolozzi, 1971

Physically Unconstrained, Destructive and Irreversible

The earliest recorded examples of facial explorations affecting the physical surface itself, were the direct result from an innovation. World War I introduced the trenches, a hand dug defensive pathway in the ground where soldiers could find shelter from enemy fire. The trench’s often limited depth turned out to be a major disadvantage because it left the soldier’s head facing the enemy uncovered. Despite the WWI survivalist mantra to: “Keep your head down,” the trenches caused many fatal deaths, and a huge number of serious head injuries.

Surgery attempted to ‘patch up’ the faces of these men to give them a more acceptable appearance, which lead to another innovation; plastic or cosmetic surgery.[39] Figure x shows an extraordinary example of this *involuntary destructive and irreversible facial exploration*. The picture reminds us perhaps of other medically induced facial deformations caused by conditions where the head, face or other parts of the patient’s bodies are deformed. A noteworthy example is Joseph Merrick better known as the Elephant Man that is thought to have suffered from a combination of neurofibromatosis type I and Proteus syndrome.[40] [41]

Cosmetic surgery’s origin in war technology has lead to an on the face of it enduring battle for beauty. A *voluntary destructive and irreversible facial exploration* has emerged that has grown into an art form of itself, with artists like Orlan and Michael Jackson serving

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[39] See Project Facade for more information: http://www.projectfacade.com/

[40] http://en.wikipedia.org/wiki/Elephant_man (07-11-2010)

[41] Another medical condition called Treacher Collins syndrome affects the cheekbone pre-birth.

as the poster childs of this genre. Figure x shows an intriguing development where progressive cosmetic surgery appears to have folded back onto its plastic self.

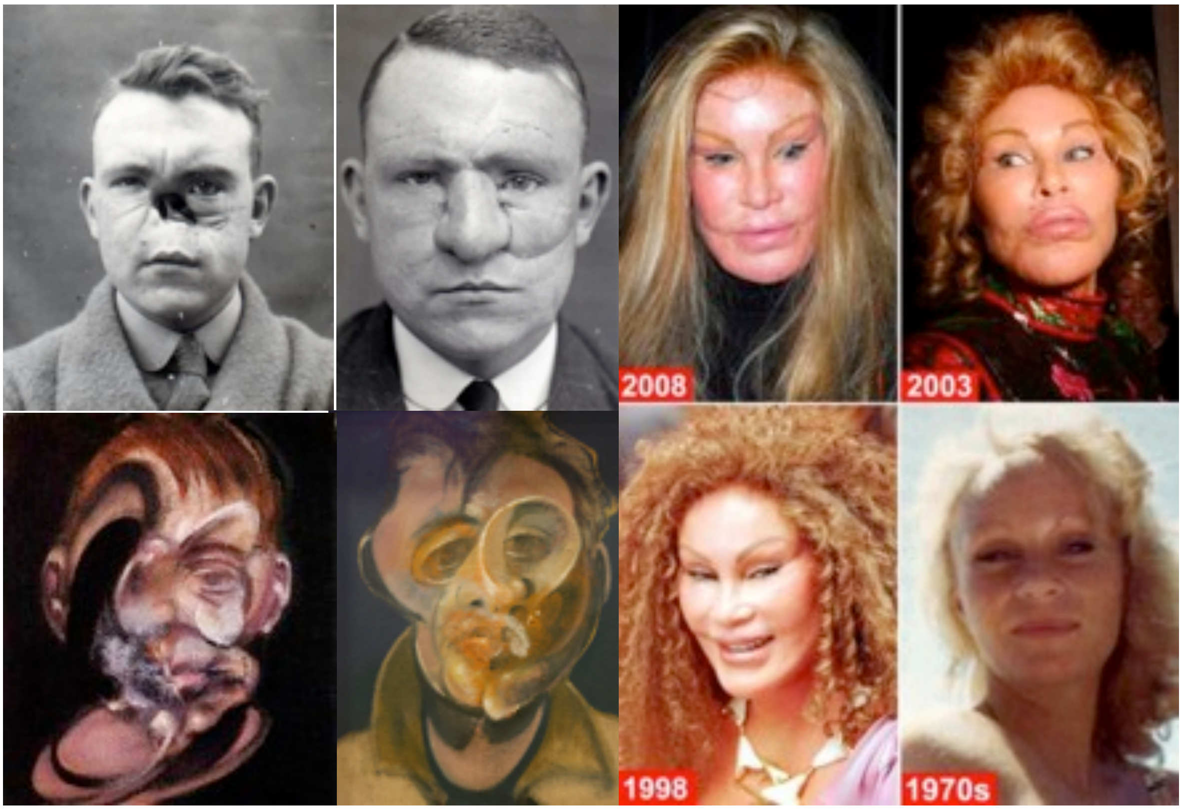

Figure 2.19: Top left; “Project Facade”, World War I plastic surgery, person, Spreckley. Bottom left; portraits by painter Francis Bacon. Right; Progressive plastic surgery on Jocelyn Wildenstein.

At this stage we should also mention the *antithesis of facial exploration*, which is a deliberate paralyzation of the face’s mobility. The *botoxation* of the face, that is the poisoning of the facial muscles, produces an inexpressiveness that has the face transformed into a lifeless mask. Not only does it impair the muscles itself, it also robs the person of an indispensable two way emotional communications channel, a system which is discussed further on in the thesis. Additionally and considering my (limited) study of the autonomous facial expression mechanism of the emotions, it is anticipated that botoxation of the facial muscles disrupts the face’s emotional feedback system. It is therefore my hypothesis that the use of botox is not merely insane, it might also lead to insanity. This claim finds some support in a recent study that found the injection of botox may adversely affect the emotional experience of the treated subjects. The botox injected group showed a lowered emotional response compared to the control group. (Davis et al. 2010)

In a doctoral thesis one is required to handle the scalpel with precision and depth, however in this thesis it seems sufficient to just scratch the surface of *voluntary destructive irreversible facial exploration*. I will for example not go into any depth about the more recent trend of embedding bulbous forehead, cheek and chin prosthetic 'adornments.' If we want to go wild in unlimited facial exploration, we should progress to the next section.

Nonphysically Constrained

Unrestricted facial exploration is possible if we leave the physical behind and just work with depictions of the face. Francis Bacon the painter is the facial contortionist par excellence, a self-declared and prolific explorer of the nervous system, by which he meant the evocation of sensational experiences. (Walsh 2008, p.85) Bacon explicitly studied facial expression as a result from various states of suffering and the tormented mind, often making use of asymmetric facial expressions that the brain instinctively interprets as a tormented mental state. Paint on canvas allowed Bacon to explore facial expressiveness and emotional response beyond the physically possible.

Figure 2.20: "Head of Invention", Eduardo Paolozzi

Less sensational unrestricted facial explorations are the cutup/collage sculptural portraits made by artist Paolozzi, but they show a level of facial decomposition that is not practically feasible on a living head.

The survey presented here will not research this category any further as depictions allow a level of facial exploration that feels like cheating as it is the research's aim to explore the real physical face. It is further my artist's opinion that constraints in general and in this case the limitations imposed by the physicality of the face are a very important artistic asset. These and previous methods have shown facial explorations that were mostly probing static facial expressions and not the face's dynamics. What is more, these methods do not allow facial expressiveness to be explored in a completely systematic manner.

Systematic Exploration

Despite the arguments against depictions of the face to explore its expressiveness, it is still worth to mention one example. Tim Hawkinson took a photograph of his face, cut it up around the facial features and attached electronically driven actuators. Driving the electromechanical actuators produces a variety of facial expressions that to some extend go beyond the physically possible. Although his system could have been used to explore facial expression in a systematic manner he seems not have undertaken any attempts in that direction.

Figure 2.21: "Emoter", Tim Hawkinson, 2002. Electromechanical facial exploration.

Figure 2.22: "Epizoo", Marcel.lí Antúnez Roca, 1994. Mechatronic facial exploration.

The same accounts for Spanish artist Marcel.lí Antúnez Roca. He built a pneumatic mechanical system of pistons and pulleys driven by electronics that could push and pull at his facial features in an automated fashion. Although his system addresses only a small subset of the facial features, it pushes or stretches the features to their natural physical extremes, but only explores some of the face's dynamics. Like Hawkinson, Roca unfortunately has not made an effort to deploy his system for systematic exploration.

As we are interested in exploring the face's dynamic expressiveness, and since arguably none of the aforementioned methods (Hawkinson, Roca, etc.) provides enough flexibility to manipulate the facial features, largely due to the limitations of the actuation mechanisms they employ and the means by which they are controlled, it occurs that we are dealing with an addressing problem.[42] Eric Tate, the facial contortionist, comes close to the ideal of direct access and full control over the facial actuators, which would enable complete systematic exploration of dynamic face space. The drawback of Tate's method though is that even while he has full facial access, systematic exploration is cumbersome to execute due to the neural origin of its control system.[43]

An essential step in the right direction was made already in the nineteenth century by the aforementioned French neurologist Duchenne. By novel means of applied and localized electricity Duchenne was able to elegantly solve the access stage of the facial addressing problem.[44] Duchenne, essentially the first facial hacker, through localized electricity and surface applied electrodes found a way to access and trigger individual facial muscles from the outside, in effect bypassing the brain. It allowed him to study individual facial muscle action; a 'living anatomy'[45] as Margaret Rowbottom notes.[46] (Rowbottom and Susskind 1984, p.72)

Duchenne's *external facial access* method created the possibility to deeply penetrate facial expressiveness without the need for a scalpel or a needle. The possibility to trigger individual muscles with ease, gave rise to the exploration of facial expressions beyond the predominant emotion related symmetric expressions. What is more, it gave him the means to explore an unprecedented combinatorial space that by voluntary neural control had been

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[42] The term 'addressing' is used in computer science as having complete access and control over something.

[43] Limitations of the neural controlling agency will be discussed in the next chapter.

[44] Duchenne's innovation was to use surface electrodes and faradic currents instead of the impractical use of needles and galvanic currents to access the nerves which was common practice by Magendie and others. Faradic or alternating currents are essential in triggering sustained muscle contraction.

[45] Duchenne used the term 'anatomia animata' (animated anatomy).

[46] In the preface of the first edition of "De l'électrisation localisée" (1855) Duchenne notes that the new ability to direct and limit the action of electricity opens an unexplored field to observation. (Rowbottom and Susskind 1984, p.72)

almost impossible to pursue. This was a great step forward in the systematic exploration of the face's static expressive space, that about a century later was extended and formalized by the research duo Paul Ekman and Wallace Friesen.[47]

It is noteworthy that Duchenne was a cutting edge researcher that made use of the latest available technologies. He was the first researcher to use the just invented medium of photography to record his scientific findings and was assisted by the most involved experts in the field.[48] Recording the first e-facial expressions was not easy as the subject had to sit absolutely still for a relatively long period of time. In his writings Duchenne complained about these shortcomings of photography and that he could only capture a still image, and not the *actual movement* of the individually triggered muscles. An indication Duchenne was genuinely interested in the facial dynamics and not just the static facial expressions.

Figure 2.23: Duchenne and an assistant demoing a first instantiation of an e-face. (circa 1862)

Now that Duchenne had resolved the facial actuator accessing problem, in effect creating the first instance of an electric facial display (e-face), full exploitation of the face's dynamics was still not possible due the very limited manual control system. Not only was the manual

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[47] The Decoding chapter will discuss this research in more detail.

[48] Namely M. Adrien Tournachon, the brother of the famous French photographer Gaspard-Félix Tournachon better known as Félix Nadar.

operation of at the most four electrodes cumbersome, it also limited the simultaneous contraction of multiple muscles, which could have significantly extended the combinatorial (static) face space. Furthermore, a high level of concurrent, structural and fast control over a large group of muscles was, given the state of technology at the time, not possible.

Complete dynamic facial control and hence exploration was only realized in the 1990s of the last century (1994) when I directly wired the facial actuators to a digital computer system. This resolved the control stage of the facial addressing problem, full unencumbered computational exploration of the facial display was now possible. An early work that I made, "The Varieties of Human Facial Expression. 12 bit version,"[49] demonstrates the power of this approach in a concurrent, systematic enumeration of static face space. It shows an expanded facial expressiveness made possible by the superior qualities of the digital computer in comparison to the neural brain,[50] that is increased speed, temporal accuracy and consistency of execution. As is shown throughout the thesis, this innovation has given rise to a new view of the face that we are about to fully explore.

Summary

The chapter provided some historic background information regarding electric muscle stimulation and the development of my artistic practice culminating in the computer controlled human face as a new expressive medium.

It presented a brief historic survey of facial exploration methods that varied from voluntary facial deformations as in gurning contests to manual facial distortions by means of mechanical aids; fingers, sticky tape or automated with pistons and pulleys. The survey also investigated destructive irreversible methods of exploration as in plastic surgery and the antithesis of facial exploration; the botoxation of the face leading to facial non-expressiveness, a facial masking activity.

It further touched upon depictions of the face through painting, photography and sculpture as a means to explore facial expressiveness, but dismissed it as not relevant for the research because of its non-physical nature. The chapter then concluded that systematic exploration of the face's dynamics with the surveyed methods employed by others is not feasible due to an addressing problem of the facial actuators, that is full access and flexible

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[49] The following Decoding chapter describes this work in more detail.

[50] As we will see, the brain is the limiting factor in exploring the face's dynamics.

control. This problem was partially solved by Duchenne in the nineteenth century by providing external facial access of the actuators by means of surface electrodes and electrical stimulation. The facial addressing problem was completely resolved by wiring the actuators directly to a digital computer system. This method allows full, systematic, dynamic and computational exploration of the face’s expressiveness.

Chapter 3

3.Decoding: Features of the Facial Display

"Primate facial displays are evolutionarily designed devices to elicit a response from the receiver." Signe Preuschoft (2000, p.257)

The human face is a unique display device which sets it apart from display systems in the inorganic world. It is a biological wetware system that is in continuous operation and cannot be shut down when not in use. It is in need of constant maintenance and for this purpose has a complex system of feeding it with essential nutrients and removal of waste products. However it is as Signe Preuschoft describes a *compound display* (Preuschoft 2000, p.256), comprising components of the face (hairy brows, fleshy lips, chubby cheeks, etc.) that through visually distinguishable states (raised, lowered, retracted, etc.) signals internal states of the operating system, the brain, to the outside world.

This compound device is surveyed on its expressive capabilities from the exterior surface down to the interior layers where the facial actuators reside. Deduced from existing facial research and my experience in detailed external control over the facial muscles, a set of external controllable facial actuators is defined. The chapter then compares the internal biological control structure to its external digital counterpart and looks at how this enables a new kind of exploration of the face's expressiveness.

3.1.Facial Function: an Interface

"It is the simple fact that I live in the facial expression of the other, as I feel him living in mine...." Maurice Merleau-Ponty (1964, p.146)

Throughout history the human face has intrigued human persons since it is arguably their most personal asset, it is the part of the body that is intimately linked to their identity. It is the site where their most personal inner states are displayed to the outside world. The human face as a signaling device, is an interface, a communications medium between a sender and a receiver. The Oxford English Dictionary designates an interface as: *"A surface forming a common boundary between two portions of matter or space."*

Since the 1960s interface is often used to describe the communications layer that sits in between a computer system and the user. The graphical user interface (GUI) with its clickable windows and icons is the common way to interact with modern computers. It is a way of connecting one thing to another by a common surface and in this respect the human face may be considered to be no different. Connectedness between the other and the self as is emphasized in the above quote by Maurice Merleau-Ponty in "The Primacy of Perception," essays on phenomenological psychology, points to this connectedness of the other in the self by looking at each others faces. Merleau-Ponty further writes: "Mimesis, or mimicry, is the power of assuming conducts or facial expressions as my own; this power is given to me with the power I have over my own body." (Merleau-Ponty 1964, p.145)

These observations made by Merleau-Ponty around 1960 are solidified by the recent discovery of so called mirror neurons that mimic other people's behavior in the brain and this is thought to form the basis of empathy. Mimicry, the simultaneous simulation of perceived facial action of an other by the brain seems a very efficient communications method. [51]

The six universal emotions: happiness, sadness, anger, fear, disgust and surprise that each have a direct neural relation or are '*hard-wired'* to specific muscular contractions in the face, are by means of mimicry signaled affectively to another person. (Ekman 2003, p.29) It is if the face of the other becomes the common surface that lies between as if it is one's own. Put differently, face to face communication is a very effective evolutionary designed system to interface one brain to another. (Preuschoft 2000) Evolution as we know is based on survival principles, to know in a glance the mental state of one's opponent, can be of crucial importance to survive.

Although humans can use their faces voluntarily to emphasize the spoken word for example, the brain's continuous exhibitionistic behavior to show off its internal state, takes high priority.[52] Given circumstances humans often experience this prioritized signaling of the

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[51] After a performance at the San Francisco Art Institute, a girl in the audience claimed that she tried to mimic the wild movements of my computer orchestrated face with her own face and said it disturbed her deeply. It might point to why people feel intrigued by a face that doesn't behave as expected, causing a 'disjunction' with the mirror neurons? It might also contribute to the fascination with the e-face.

[52] For completeness, not all features of the face can be voluntarily controlled, e.g. tarsalis has been shown to be outside control. (Ekman and Friesen, 1976)

inner emotions on the exterior surface as undesirable and attempt to suppress this unwanted behavior. Philosopher Emmanuel Levinas typifies the loss of control over one's own face as if the face *resists possession*. (Levinas 1969, p.197) Humans for this reason engage in a facial masking activity that seminal facial expression researcher Paul Ekman calls "facial management." (Ekman 2003, p.140)

Ekman found facial management to be flawed due to limitations of the brain's neural origin and emotions for this reason will leak onto the face despite active suppression by the person in 'charge.' Neural latency, the slowness of neural processing, causes delays between detecting an imminent muscular contraction and the action of releasing it. Neural action takes place in the millisecond range and because of this, for a fraction of a second, emotion related expressions are visible on the face. *Micro-expressions*[53] as Ekman calls these fleeting emotions, can be detected by careful study of faces recorded on video[54], and by this means Ekman claims to be able to tell if a person for instance is lying.[55] [56] (Gladwell 2002, p.7)

These factors perhaps contribute to peoples' obsession with their faces, while it is the part of the body that identifies them as individuals, it is also the part that exposes their innermost personal feelings and at the same time is beyond their own control. Excessive nurturing of the exterior surface, might therefore be an attempt to regain control over the interior.

3.2.Facial Appearance

The face as an interface as discussed, in its original meaning is *form*, *visage* or *appearance*, from the Latin *facies,* which also means *front*, *surface* as in a *façade*. It is the overall appearance of the face that is investigated, identifying where the action takes place and based upon this regions and directionality of movement are defined. As excellent information can be found on the anatomy of the face, the discussion is tailored towards the aim of the research; devising a strategy for effective computational facial exploration.

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[53] Perhaps a more correct term would be milli-expressions as neural latency takes place in the millisecond range.

[54] The magic of photographic portraiture might lie in the snapshot capturing of these fleeting emotions. I think that for this reason a good photographer always talks to their subject in order to elicit emotions.

[55] Not surprisingly intelligence agencies are interested in Ekman's work.

[56] My hypothesis is that leakage of emotions onto the face might be masked by increasing muscle tonus through the application of a bias level of electrical stimulation to nervus facialis. Politicians might be interested in such a dedicated e-masking device.

3.2.1.Attractors

The Myology section of the appendix describes the kinematic system of the human face and identified the three most important orifices in the face, two smaller ones in the upper part, housing the eyes and a larger one in the lower part constituting the mouth. Dilator muscles pull directly or indirectly at the sphincter muscle surrounding the orifice, locally shaping the face into deformations.

From a perceptual view of the face the orifices of the face serve as perceptual attractors or focal points because movement revolves around these facial openings. Movement as Jonathan Benthall notes in "Science and Technology in Art Today" (Benthall 1972, p.101) is perception, without movement, whether this is the scanning of the eye of a static image or the actual movement of objects in space, there is no sense of perception as such. Perhaps this is overstating the issue that perception relies on motion, but it points to the fact that motion is change and some type of change is needed in the retinal cones of the eye to operate, the eye thereby functions as a sensitive motion detector. Additionally, the eye is never motionless, even when the eye is utmost fixated a so called *microtremor* moves the eye with a very small amplitude in a frequency of 20 to 150 Hz. (Schmidt 1986, p.191)

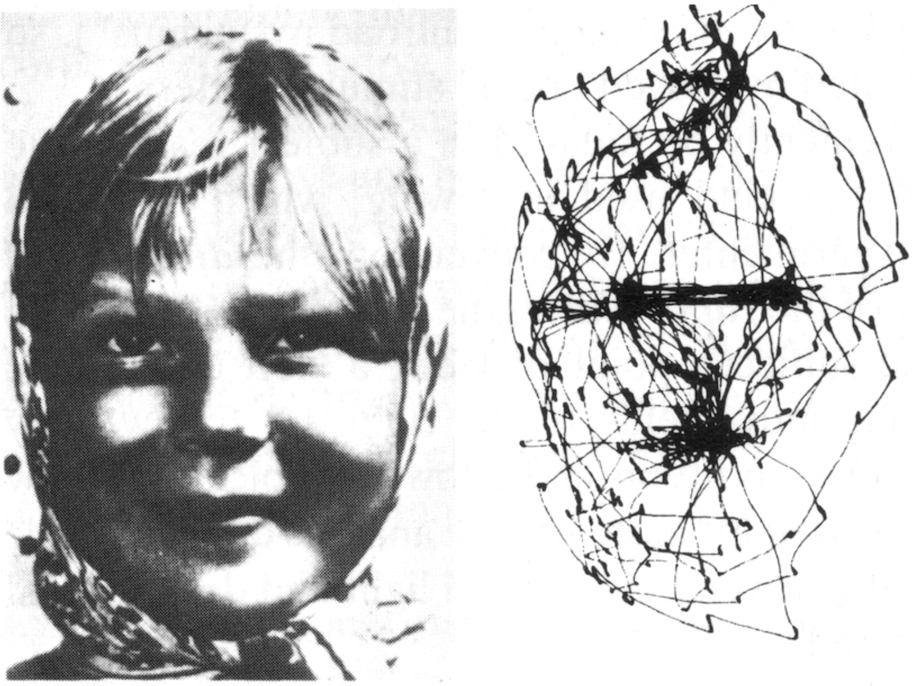

Figure 3.1: An electrooculogram showing eye fixation points on the perception of a photo of a face. (Schmidt 1986, p.196)

The designation of attractor points is evidenced by illustration figure 3.1 taken from a textbook on sensory physiology by Robert Schmidt. (Schmidt 1986, p.196) It shows the two-dimensional record of the sequential eye movement fixation positions of a subject viewing a photo of a face for several minutes. The eyes and mouth are fixated particularly often and a preference for the right side of the face is seen. (For the technically inclined; the movement of the eye from one fixation point to another is called a *saccade* and takes between 10 and 80 ms. Fixation periods between the saccades last between 150 and 400 ms. For a variety of reasons during a saccade no movement is perceived.)

Because movement is the essence of facial expressiveness, movement attractor points are designated to the orifices. The eyes and mouth are the three most apparent orifices of the head and are designated the most important attractors. The nostrils also in the front of the head can also be moved, but they have a very limited expressiveness. Instead the nose itself is designated an attractor point because movement of the face as a whole revolves around this central point of reference.

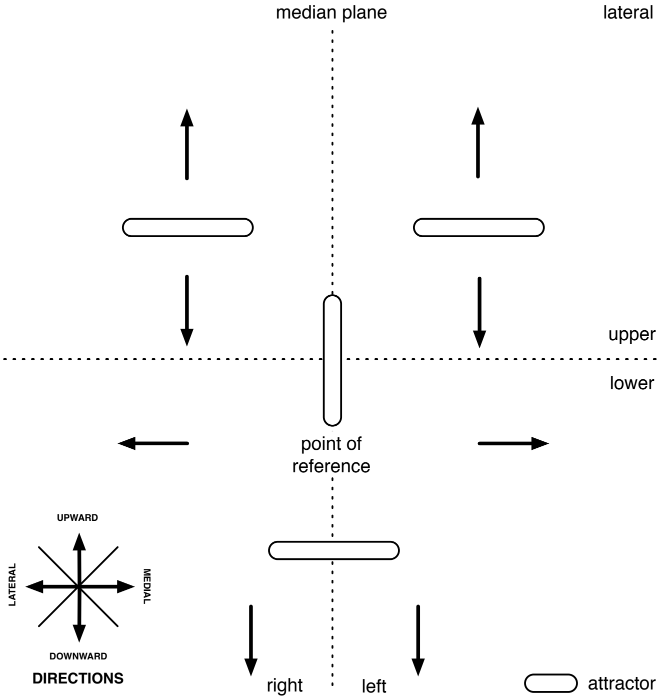

Figure 3.2: Facial topology; regions, attractors and directions.

Figure 3.2 illustrates the facial topology where directionality of movement and proportions of facial deformations play an important role in designating the nose an important attractor point. This is attributed by the above electrooculogram[57] as it shows the eyes of the viewer frequent the nose. The remaining orifices of the head, the ears have an extremely limited repertoire of movement and are therefore omitted as attractors.

3.2.2.Regions: upper/lower

Facial movement as just pointed out revolves locally around the orifices in the head and this movement has no or very limited affect on other parts of the face. The movement of the mouth for example has no physical affect on the area around the eyes and vice versa. This physical inference suggests a regional division of the face into an upper and lower part. Many researchers have acknowledged this upper/lower division of the face.[58]

3.2.3.Regions: left/right

The division in an upper/lower face to an untrained observer is less apparent than the distinctive left/right symmetry of the face and human body as a whole. In medical terms a vertical *median plane* divides the two halves of the body, and therefore anything related towards the median plane is referred to as *medial* and anything towards the sides of the body as *lateral*. (Figure 3.2)

For this reason a left/right division of the face can be added to the upper/lower division, sectioning the face into four almost independent regions: upper/lower and left/right. Because the mouth is located in the middle of the face and muscle pull on one side has a deformative affect on the other, the division into four independent regions is somewhat simplified, but will turn out to be a workable model when logical operations on the face will be defined.

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[57] An electrooculogram is a method to measure eye movement by measuring electrical potential between electrodes placed close to the eye.

[58] Duchenne notes that although no physical change affects a non-moving part, on the overall perceptual level an affect is noticed. Perhaps gestalt and mimicry play a role in this perceptual inference.

3.2.4. Directions and Proportions

Figure 3.3: Changing Proportions of the face affected by facial movement.

The frontal view of the face appears as a two dimensional surface, where movement of facial elements change the proportions of the perceived plane. This is most notable by the raising of the eyebrows and the lowering of the lower lip because it gives the impression the face in the vertical dimension has elongated. Lowering the brow of course has the opposite effect. Both movements have a vertical directionality. Contracting the muscles of joy, pulling the cheeks laterally outwards, has a horizontal directionality that also changes the perceived proportions of the face. Figure 3.3 illustrates how the perceived proportions of the face change by facial movement. The cutouts resemble a rectangular area spanning apex positions of the eyebrows, lower lip and cheeks.

Based on the above survey of facial appearance, a facial topology is drawn up in figure 3.2 illustrating attractors, left/right, up/down regions, and movement directions.

3.3.Facial Action

The individual moveable elements that make up the different regions of the face, roughly the eyebrows, lips and cheeks are operated by a set of muscles beneath the skin that by their contractile action deform the surface into a variety of shapes that we call facial expressions. It is inevitable for research into facial expression to study the anatomical construct of the face. This section surveys in chronological order the most notable work done in this area, starting with Duchenne de Boulogne who mapped the facial muscles directly onto their emotional relationship.

It will then move on to the Swedish anatomist Carl-Hermann Hjortsjö that extended Duchenne's work to include all sorts of head movements as part of the expressive repertoire. Researchers Paul Ekman and Wallance Friesen then picked up on Hjortsjö to extend the vocabulary of the face to include for instance facial punctuation in conversation. To date the most comprehensive and systematic study in categorizing facial expression was done by this duo and was described in the Facial Action Coding System.

3.3.1.Muscles of Emotion

It is obvious different parts of the face can be moved to other positions, but how the individual muscles beneath the skin exactly attribute to surface deformations is not easily understood. It was renown French neurophysiologist Duchenne de Boulogne who by novel means of localized faradization[59] studied the contraction of the individual facial muscles to

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[59] Duchenne insisted induced instead of galvanic currents should be used for medical stimulation of the nerves and muscles and proposed to use the term "faradization" after Faraday their discoverer. (Rowbottom and Susskind 1984, p.75)

produce the typical surface deformations denoting different emotional states. Duchenne conceptualized the human facial surface almost as a canvas when he wrote: “Armed with electrodes, one would be able, like nature itself, to paint the expressive lines of the emotions of the soul on the face of man. What a source of new observations!” (Duchenne 1862, p.9) He localized *points of election*, now usually called motor points,[60] that indicate precisely where a nerve enters a particular muscle. This identifies individual muscles of the face to a set point which Duchenne named after their emotional relationship as e.g. the muscle of joy, the muscle of sadness, or muscle of reflection.[61] (See Appendix E and figure 3.4.)

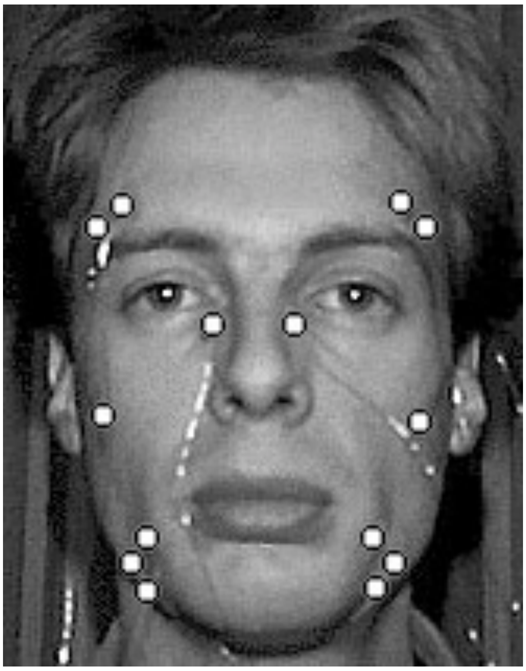

Figure 3.4: Most used access points of the face.

The motor points naturally indicate the muscle’s anatomical position in the face, but from these indicator points it cannot be determined precisely how the muscle contractions shape the surface of the face. If for example the muscle of contempt is triggered laterally, it produces a pronounced upward medial movement of the brow, while laterally lowering it just a little. Around the mouth piece surface deformation is even more complex and the relation to the motor point is not obvious at all. The cause lies in the anatomical construct of the orifice where the orifice is surrounded by a sphincter muscle that itself can contract and the dilator

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[60] Throughout the thesis these points are often referred to as *access* or *control* points to emphasize external control of the muscles.

[61] This work is still regarded among his most important achievements. Although in medicine Duchenne muscular dystrophy, a degenerative muscle disease, is regarded his most important contribution to science.

muscles that at the same time can pull at this muscle in a variety of ways. In addition the muscles themselves are arranged in a complex layering, this all taken together causes the skin to fold and bulge in ways which are hard to determine.

Duchenne's research of directly mapping the facial muscles onto their related emotional state, which he described as the *language of the passions* is important[62] and most of his findings are still valid today. It serves as a solid fundament for other researchers to expand upon, which is discussed next.

3.3.2.Mimic Language

The Swedish anatomist Carl-Herman Hjortsjö picked up on Duchenne's notion of a facial language and modeled facial expression into a *mimic language.* In the preface to "Man's Face and Mimic Language" Hjortsjö describes individual muscle contraction as letters in expressive words and these words combined as sentences comprising more complex expressions. (Hjortsjö 1969, p.5) He further added the notion of co-movements to include for example head postures, gestures, chewing and gaze. Although Duchenne provided the notion of a language to designate facial expression, Hjortsjö added the component model to describe complex facial movements. Language and component model are essential elements for the design of the computational explorative language that is described in the encoding section.

Hjortsjö as an anatomist further made an important observation about the frontalis muscle, the raiser of the brow. Until then it was thought to be capable of a single action, but Hjortsjö found could raise the brow on the medial and lateral sides separately. A refinement acknowledged by Ekman and Friesen in the next section. (Ekman and Friesen 1976)

3.3.3.Facial Action Coding System

To date Ekman and Friesen conducted the most comprehensive study into facial expression and extended and formalized Duchenne's and partly Hjortjö's work. Their influential paper "Measuring Facial Movement" states their aim: "Our primary goal in developing the Facial Action Coding System (FACS) was to develop a *comprehensive* system which could distinguish all possible visually distinguishable facial movements." (Ekman and Friesen

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[62] Duchenne likened the importance of his research to the discovery of perspective and its impact on painting.

1976, p.2)[63] Emphasis added by the authors to denote they were not only interested in designing a measurement system for the emotion signals, but also non-emotional facial movements like e.g. facial punctuation in conversation. Their research investigated all possible facial action combinations that can be performed voluntarily on a human face, thereby ignoring the tarsalis muscle as it can't be operated voluntarily and has no valuable visual appearance. The duo makes note of the research as *comprehensive* as a way to be theoretical bias free.

Because facial motion is driven by the facial muscles, Ekman and Friesen naturally worked from the anatomical basis of individual facial muscle action and tried to identify minimal *Action Units* (AU's) comprising unique discernible visual facial movements. Since FACS is a facial expression scoring system it is based upon observation of facial action, and therefore visual perception plays a crucial role in their approach.

AU's are mostly anatomically defined based on individual muscle action, but for perceptual reasons a few muscle contractions are grouped into a single unit. Action units designate clearly visible muscle contraction, ignoring those that have invisible muscle tonus effects or are just too subtle. In some cases a deviation from the anatomical basis followed Hjortsjö lead, for instance defining lateral and medial parts of frontalis as separate action units.

The Facial Action Coding System is an objective method for quantifying facial movement in terms of component action and is widely used in behavioral investigations of emotion, cognitive processes and social interaction, and also in CGI (Computer Generated Imagery), where it informs the engineering of computer-animated faces.

FACS lists a total of 46 single Action Units and an additional 11 AU's that define facial gestures like e.g. lip wipe or the sticking out of the tongue. Both are listed in the appendix and exclude Hjortsjö's co-movements because FACS only encompasses movements of the face and not the head as a whole. Ekman and Friesen also designed a limited FACS system, called EMFACS that only describes facial action related to emotion. EMFACS could not be surveyed as it is only available commercially (..), but it seems likely to be very close to

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[63] Article also available online at: http://face-and-emotion.com/dataface/facs/guide/FACSIV1.html

Duchenne’s categorization of the muscles of emotion including some collapsed AU’s and the lateral and medial part designation of the frontalis muscle.

Having Duchenne’s muscles of emotions, Hjortsjö’s mimic language, and the extensive FACS system, raises the question what facial elements can be used to define the e-face or more specifically what actuators can be controlled externally. In practice I have found that many of the FACS-defined action units are irrelevant, either because they are too subtle, or just very difficult to implement by electrical means. The next section, External Controllable Actuators, discusses restrictions of electro-facial control and consequently identifies which muscles can be controlled externally without much difficulty: the so called electro-expressive muscles.

3.4. External Controllable Actuators

The facial anatomy has a construct which sets it apart from the rest of the muscular system of the human body. While it enables a unique exploitation of the face’s dynamics, it also poses a few constraints on for example accessibility from the outside by surface electrodes. The electro-expressive muscles are delineated by above factors and issues of visible relevance of the induced expressions.

3.4.1. Some Anatomical Inferences of the Face Relevant to Dynamic Exploration

The facial musculature has a unique anatomical construct that allows for a unique exploitation of its dynamics. Compared to the muscles of the skeletal locomotor system, where precise and smoothly controlled movement is made possible by a force counterbalancing antagonist-protagonist system, the facial musculature does not have such a clear antagonist-protagonist structure. The seventh cranial innervated facial muscles or the muscles of mimicry, individually just pull to deform the facial surface. Although the layering and interconnections of the muscles in the face is complex, an individual expressive muscle has no direct counteracting pair muscle.

Because a contraction of a facial muscle is typically not counteracted upon by a directly opposing antagonist, and the muscle is tightly fixed only at one side (the origin), to stable bone structure, it can move more freely than the muscles of the locomotor system.[64] Due to this fact, together with the viscoelastic properties of muscle and skin tissue, facial muscle behaves much like a one sided attached spring. (Parke and Waters 1996, p.225) These anatomical inferences make possible extensive exploitation of its dynamics, which will be evidenced in the exploration of resonance phenomena in the face and discussed as a parameter in the section on Muscle Resonance which follows later in this thesis.

It also answers a common question about electro-facial stimulation, whether one can voluntarily fight against an externally triggered muscle. Lacking a clear antagonist-protagonist muscle structure, the brain can only resort to an attempted relaxation of the contracted protagonist.[65]

3.4.2.The Mouth a Special Case

Electric stimulation of the seventh cranial innervated muscles is quite straightforward, but some expressive movements of the face are more difficult to control externally. The muscles controlling the opening and closing of the mouth, the masseter (AU 26) are innervated by the fifth cranial nerve trunk and are at both sides connected to bone structure which restricts its free movement. Opening and closing of the mouth is a concerted movement of the different parts of the masseter and a couple of other muscles.

Lowering the mandible, as Duchenne already noted, is a voluntary action instigated by the relaxation of the masseter muscle, since by default the mouth is kept closed through muscle tonus. The platysma muscles, the plate like muscles of the neck, which pull the skin of the face downwards further contribute to the opening of the mouth. (Duchenne 1862, p. 89-92)

In electro-facial control, the opening and closing of the mouth, an important dramatic effect, relies on the subject to relax the masseter muscles, which is counter-natural behavior while awake. The external electronics then take control of the masseter. Releasing the

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[64] Some facial muscles are connected on both the origin and the insertion side to soft tissue, e.g. orbicularis oris.

[65] A related question often asked is if one feels the same as the externally triggered emotion, from my own experience I would say “no.” In my performances though, many different (non-emotion related) muscle configurations follow each other up in a rapid succession; the supposed emotions therefore are too fleeting to dwell on. Perhaps this resembles the post-modern state of mind. Despite the assumption that facial muscles have no muscle spindles, facial positions and movement is fed back to the brain through receptors embedded in the skin. (see Appendix B.3 Muscle Action)

masseter and simultaneously contracting the platysma will then open the mouth. In performance practice this has problems due to the need to continuously stimulate the masseter to keep the mouth shut. As the facialis nerve trunk passes over the masseter, it will be *parasitically*[66] electro-stimulated by the continuous stimulation of the masseter. Therefore the opening and closing of the mouth is done solely through stimulus of the platysma muscles while the subject itself keeps a masseter tonus just strong enough to raise the mandible.

Gleaned from the above, dynamic exploitation of the fifth cranial innervated muscles and in particular the masseter is not easily possible. For this reason the opening and closing of the mouth in electro-facial choreography will be treated as a special case.

Talking about the mouth, the mouth sphincter muscle itself is rarely electro stimulated and is discussed next.

3.4.3.Omissions

A few moveable facial elements are completely excluded from electro-facial choreography as these elements of the face are too subtle in its appearance or too difficult[67] or too uncomfortable[68] to control externally. The most eye catching in this respect are the sphincter muscles that open and close the eyelids, orbicularis oculi pars palpebralis (AU 7) and orbicularis oris pars marginalis and pars labialis (AU 22, 23, 24) that surround the mouth. The muscles operating the nostrils and the nose wrinkler, respectively nasalis and the different parts of levator labii superioris. (AU 38, 39, 9)

These and the aforementioned involuntary muscle tarsalis are the most important expressive muscles that are excluded to act in electro-facial choreography, because they are hard to trigger externally or too subtle in expressiveness. Although future research might devote attention to incorporate these muscles into the system as well.

3.4.4.The Electro-Expressive Muscles

Considering the above discussion, Duchenne’s muscles of the emotions, the action units from FACS and muscle exclusions based on observations made in external muscle control, the

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[66] Parasitic as a term is borrowed from a notion in high frequency electronics engineering of components having undesired properties or side effects, e.g. an inductance having a capacitance: parasitic capacitance.

[67] Some muscles are hard to reach with surface electrodes as they are deeply embedded under other tissue.

[68] See the discussion of comfort issues of electro-stimulation in Appendix C.

most important electro-expressive muscles of the human face can be defined. A summary defining so called *access points* is given in Appendix E.4 and graphically represented in figure 3.5. It provides the access point locations on the face, directionality of movement and muscle pull vector. The muscle pull vector is roughly indicating location and direction of the visible deformation as this is often not easily deducible from the access point.

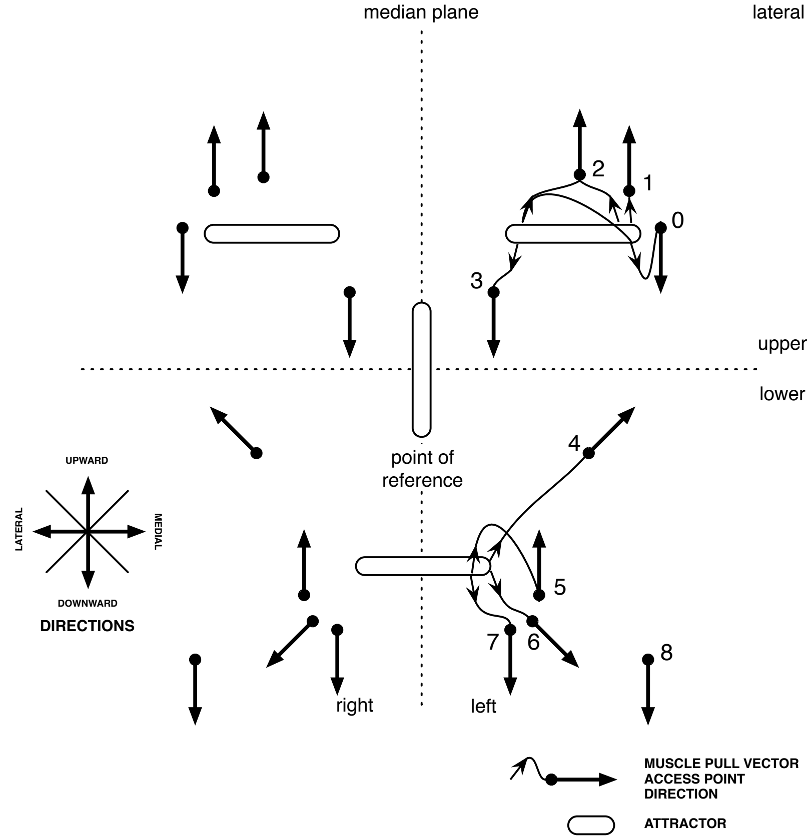

Figure 3.5: The Electro-Expressive Muscles.

The electro-expressive muscles are the fundamental actors in electro-facial choreography and are a subset of the available facial muscles that largely correspond to the universal emotion innervated muscles.

3.5. Expressive Potential: Static and Dynamic Face Space

"There is, in the human face, an infinity of twists and turns and escape routes."
Georges Bataille (1944) [69]

The introduction gave a brief description of the human face's expressive potential as a combinatorial space of possible facial expressions; the so called *face space*. This space of facial possibilities is delimited by the physical capabilities and the amount of actuators. The more operating actuators, the larger the space of possible output states or facial deformation patterns.

Because of the complex layering of the muscles, the wrinkling of the skin caused by the resultant of the different pulling muscle forces, it deforms the surface of the face in an enormous variety of patterns. The space of possible facial patterns is very large and hard to quantify. Ekman and Friesen estimate the combinatorial space to be about 10,000 different facial expressions. (Gladwell 2002, p.4) In "The Varieties of Human Facial Expression. 12 bit version," I have made a live recording of the whole combinatorial face space of twelve facial muscle binary (on/off) states, which resulted in 4096 different muscle configuration patterns. (Figure 3.6) Because the space is binary defined, adding a single muscle, for instance tarsalis, the combinatorial space grows exponentially by a factor of two. If the intermediate contraction states of the muscles were incorporated, i.e. the continuum that spans the full range from fully relaxed to fully contracted, it is not hard to imagine the size of the combinatorial space would become very large, likely infinite.

The combinatorial space so far is defined by the muscle's expressive end or static states, and therefore should more correctly be named *static face space*.

If the face as a malleable surface is considered in the temporal domain, a second combinatorial space can be defined that is based on facial movement patterns and sequences of these patterns. In complement to static face space the research dubs this space *dynamic face space*. It not only defines transitions from one static expression to another, but also how movements evolve over time, like in a choreography.

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[69] Secondary source: "Face, The New Photographic Portrait" by William A. Ewing (Ewing 2006, p.52)

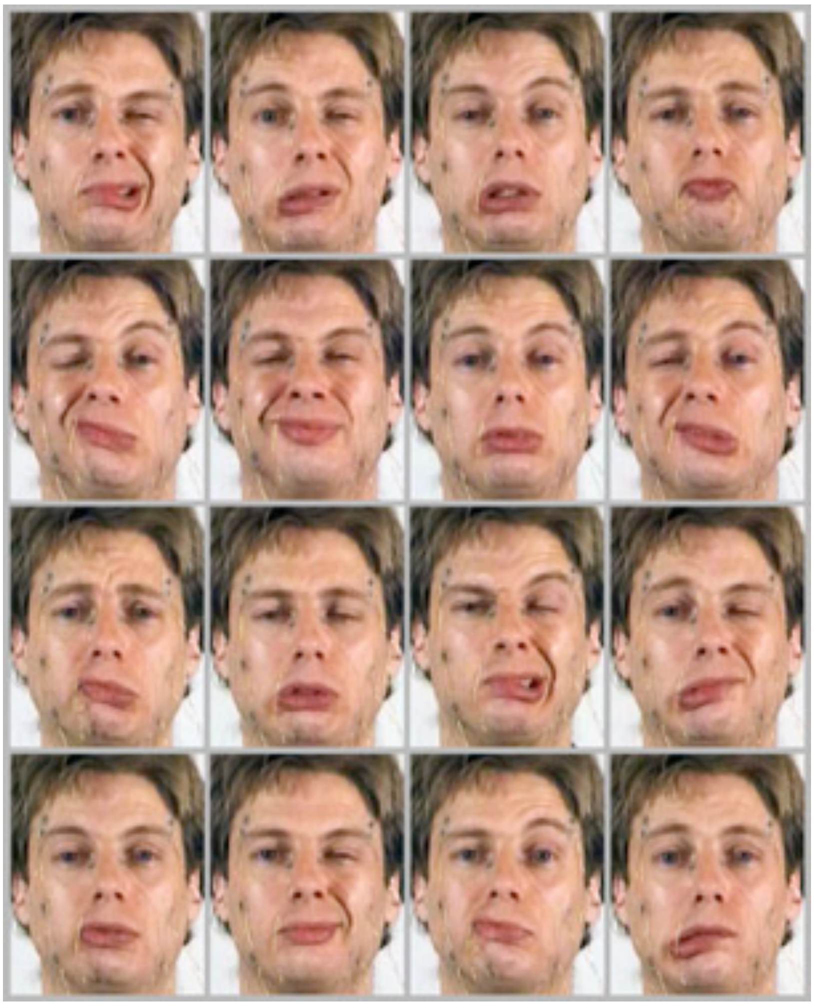

Figure 3.6: A random sample of muscle contraction configurations, video stills from "The Varieties of Human Facial Expression. 12 bit version." Elsenaar 1997. Videography: Josephine Jasperse

The face's expressive potential therefore includes a static and a dynamic dimension that defines the human facial display as a kinetic, choreographic medium. The chapter on electro-facial choreography explores and defines this in detail.

3.6.Agency: Neural versus Digital Control

"Elk voordeel heb z'n nadeel."[70] Hendrik Johannes Cruijff (A renowned Dutch dancer)

The face as a display device has been defined now as a space where action takes place and identified the actors that populate this space. The mechanism or agency behind the orchestration of the action to a large extent determines how the actors can perform. In its natural operation, the facial muscles are innervated by the fifth cranial nerve trunk that carry the signals from the brain's "emotion dispatch center," the facialis nuclei. The different

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[70] Translation: "Every advantage has its disadvantage."

emotion centers in the brain send their inner states to the facialis nuclei and subsequently they are displayed as corresponding facial deformation patterns. The face as a canvas where the emotions are painted onto by the neural agency has already been discussed, so it will not be repeated here.

Besides the autonomous dispatch of the emotions, the brain can of course also orchestrate the face voluntarily. Some prime examples of neural facial exploitation are shown in the background chapter with the remarkable Eric Tate as the quintessential facial contortionist.

Voluntary or involuntary, the biochemical origin of neural operation is the delimiting factor in how the facial actuators can be orchestrated. Biochemical neural processes are quite slow, they have a temporal resolution in the millisecond range and lack operational consistency. Neural systems further require extensive levels of training to have the system perform tasks with a high level of consistency and accuracy. This is of course evidenced in the lengthy process of learning to play a musical instrument (such as the violin, piano or oboe) or in the aforementioned Kathakali facial dance. The programmability factor of neural systems is rather poor.

In contrast digital computer systems can be programmed instantaneously with ease, where its operation is completely deterministic. Digital systems further are much speedier than their neural counterpart, with speeds in the range of nanoseconds. Consequently temporal accuracy and consistency of operation are superior qualities of digital systems.

If a “regime change” is allowed from neural to digital, it is to be expected facial performance could be extended by these superior properties. Indeed, my work has shown external digital control over the facial muscles increases accuracy and consistency of facial behavior. As such it is postulated that facial behavior to a great degree is determined by the qualities of the controlling agency, thereby inheriting its characteristics. While the actuators can be programmed with digital precision, the physical properties of the facial construct pose the ultimate performance limits and not the controlling agency.[71]

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[71] The encoding section investigates the facial actuator performance parameters within the digital agency’s context.

Given that the face behaves as an extension of a system, the old adage that the face is a reflection or mirror of the soul may now be reframed in light of the possibility of artificial control.[72] The facial display has become a site for digital computational expression.

3.6.1. Emotion to E-motion

Writing expressions on the face can be done in two ways, by the internal neural agency or externally by a digital computer sending stimulating impulses to the facial muscles. Considering Duchenne's work François Delaporte signifies the last method as *electrography* (Delaporte 2008, p.137) and likewise the first method could be named *neurography*.

Electrography is fundamentally different to neurography in the way the facial actuators are controlled by electrical signals. Electrical control makes use of a closed circuit in which a small current flows from the exciting electrode (cathode) to the anode, along its path triggering any excitable tissue (muscles and nerves), not just the intended muscle, leading to possible parasitic stimulation. Neural control of the muscles is different as signaling the muscles through the nerves takes place by means of a propagation wave. In a sequential process of polarizing and depolarizing across cell membranes an electric signal can travel along the nerves to arrive precisely at the motor plate of a muscle triggering it into contraction. No electrical current flows in this scheme and therefore neural control is not suffering from parasitic side effects as the artificial counterpart does.[73] In essence the technical difference between electro- and neurography is current driven versus signal or voltage driven control of the muscles. Additionally, the application of the electrical impulses by means of externally applicable electrodes is less precise than the direct innervated muscles, because of this in theory electric control would suffer from a reduced resolution of facial expressiveness.[74]

Besides the physiological differences between the two control schemes, a far more important difference is the just discussed agency. The regime change from neural to digital allows the face to be explored in an unprecedented systematic manner. The discussion of the

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[72] It could perhaps be argued 'soul' is indiscriminate, but to say a digital computer has a soul is more like talking about worms in a can than anything else.

[73] Tissue current flow does have some other side effects like thermal heat up and electrolysis.

[74] In practice, as evidenced by my work, parasitic and less precisely localized stimulus has very little effect on the overall appearance, although it can provide a bias tonus to non-targeted muscles reducing its dynamic range.

expressive potential of the face, gave “The Varieties of Human Facial Expression.” as an example of the sizing of static face space. From a dynamic viewpoint, “The Varieties” is also an excellent example of the change agency makes in exploring the facial display. A large combinatorial muscle contraction space is generated on the face without much effort. While at the same time the *e-face* shows strict, precisely programmed, movement patterns that the neural agency would never be able to accomplish.

Perhaps the net result is that the e-face conforms to the old modernist motto of “form follows function” or expressed differently it becomes a reflection of a so called “machine aesthetic” as R.L. Rutsky discusses in “High Technē.” (Rutsky 1999, p.12) At least it can be inferred that the human face has entered a new *post-neural* explorative phase where it has moved away from the display of the emotions towards an abstract display of pure electronic motion: *e-motion*. The human face becomes a portrait of computation.

3.7.Exploring the Expressive Potential of the E-face

Following the proposed hacking approach to explore and define the e-face’s expressive potential, decoding the facial display uncovered two layers of information. Appearance and agency are the two key elements in facial expressiveness, where appearance defines the moveable elements in the face within the structure of the head’s front. Agency has two variations, natural/neural and artificial/digital and each provides a different quality of control over the facial actuators.

This information informs how the facial display can be explored, it imposes structural limits and provides new opportunities. The structure of the face and how the actuators are embedded within it, is a given that cannot be diverted from. It informs and narrows face space because the array of actuators is not indiscriminate, but are grouped around the localized facial attractors.

The agency can be diverted from as it can be changed from a neural to a digital control scheme. External digital control allows the expressiveness of the e-face or dynamic face space to be formally explored by digital computational methods.

Choreologic probing is an explorative scheme that deploys systematic computational methods in a confined face space to find and identify typical e-choreographic facial movement patterns. Probing dynamic face space with such rigour is unprecedented and it is expected and shown to unveil previously unknown facial movement patterns.

The Encoding chapter that follows presents practical and conceptual tools to effectively explore dynamic face space.

Chapter 4

4.Encoding: External Control of the Facial Display

The systematic exploration of dynamic face space requires practical and conceptual tools to efficiently control the facial musculature externally. In this chapter an innovative, effective and safe digital facial muscle stimulus system is described that allows detailed control over the facial muscles.

Controlling the facial components in a structural and efficient way, a computational explorative framework is designed and instantiated in the form of a language specification, the *Language of Facial E-motion*. It is based upon the topological analysis of the face into structural components as discussed in the previous chapter, and theoretical logic operations on sets of actuators; a choreologic of the e-face. The framework is complemented by essential e-choreographic parameters such as facial component displacement speed and digital muscle resolution. The chapter concludes with the deployment of the language in a series of systematic experiments to determine the fundamental e-choreographic movement patterns.

4.1.Facial Muscle Control System

This section chronicles the most important design issues of a next generation digital facial muscle stimulus device that is tailored towards stage use. It is based upon the previous generation of devices that I have developed, with an emphasis on increased comfort and safety of the stimulating electric impulses. It further aims to improve on the ease of use of the device in a stage context. The reader is referred to Appendix C for a discussion of the various issues involved in applying electrical currents to the human body, which include the different types of electrical stimulus impulses, mono-phasic versus biphasic stimulus, issues of comfort, and electrode placement and size. In this section the key issues about the design of the device are discussed, elaborate design decisions on the choice of electronic components are left out of the discussion as it is not essential. Although Appendix D does provide an electronic block diagram and an assembled prototype listing specific electronic components.

At the time of writing this thesis, the next generation is already in development, which is based on the knowledge gained in developing this device. Full electronic schematics and software will be open sourced and made available online; see Future work section.

4.1.1.System overview

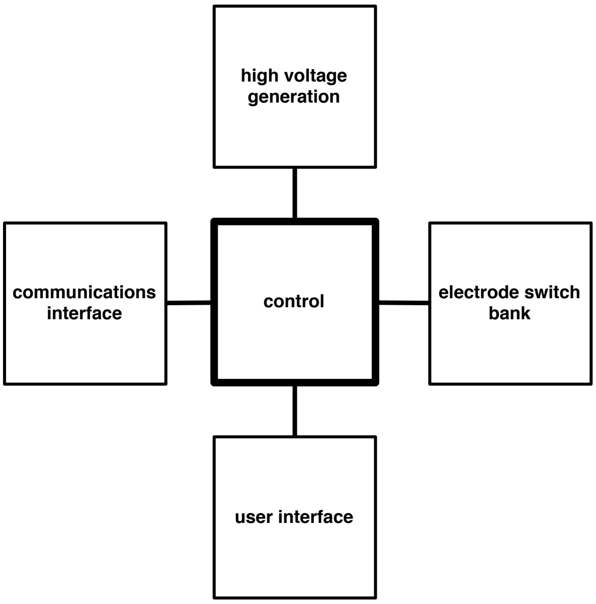

Figure 4.1: Facial Muscle Control system, functional block diagram.

A facial muscle control system needs to be able to safely and accurately provide a detailed level of control over the e-expressive muscles. The basic premise of safety of electric nerve stimulation is to control current levels and current path through the body as discussed in Appendix C. A further requirement is concurrent control over the muscles, so the e-expressive muscles can be controlled simultaneously without interference. Programming complex e-choreography pieces further requires a host computer system that communicates with the device through a safe communications medium.

Figure 4.1 illustrates the basic functional blocks of such a system. A brief description of each block's functionality is presented to provide a general understanding of the facial muscle stimulus system that is designed.

Control — Central to the system is the control section, it consists of a microcontroller that handles all tasks of the other parts of the system. It serves as a dispatch center and as an electrical pulse train generator for the multiplexed stimulation of the muscles.

High voltage generation — Electrical stimulation of muscles requires a relatively high voltage level to overcome the high resistance barrier of the skin.

Electrode switch bank — Simultaneous control over a relatively large number of electrodes requires an evenly large number of electrode switches.

Communications interface — The facial muscle control system is designed to be a rather dumb device, that generates the required voltages and electrode switching, but has very limited functionality of its own. Orchestration of the facial muscle's intensity levels is done on a host computer, the device itself just 'relays' electrode intensity information received over a safe communications channel.

User interface — The user interface provides basic operational control to the user. It allows the user to calibrate muscle onset and apex current levels and provides real time feedback on the individual muscle's current levels. A small color LCD screen and thumbwheel are used for this purpose. (Figure 4.4)

4.1.2.On Stage Requirements

Stage performance adds to the feature list of a facial control system because it requires the system to be used in a conceivably dynamic environment. Safety, portability, reliability and usability are key factors in this context. The next section will discuss these additional requirements in detail.

4.1.3.Features and Improvements

The last generation of devices I developed, and used for many years, have many of the required features. Let us investigate in detail how the last generation compares to these required features and stage requirements. It will describe the current technical implementation and discusses possible improvements for the new stimulus device.

4.1.3.1.Concurrent facial muscle stimulus

Simultaneous electrical stimulation of the facial muscles or nerves has mainly two technical solutions. The most common one is the bipolar and biphasic stimulus method as discussed in the Appendix C. It usually stimulates the muscles in parallel with two electrodes located close to the motor point of the facial muscle.

The second method of concurrent muscle control, is the mono-polar and mono-phasic setup, that sequentially stimulates the muscles, in a technical scheme called multiplexing. This is the method that I have pioneered and which has remained unchanged throughout the development of different device generations.

In this scheme, a typical characteristic of pulsed direct currents in the context of muscle stimulation is exploited. The diagram in figure 4.2 illustrates the relationship between pulse width and pulse frequency; a narrow pulse of at the most 1 ms duration is repeated after typically 20 ms. The on/off ratio of about 1:20 is leaving an inactive gap where other pulses (channels) can be inserted.[75]

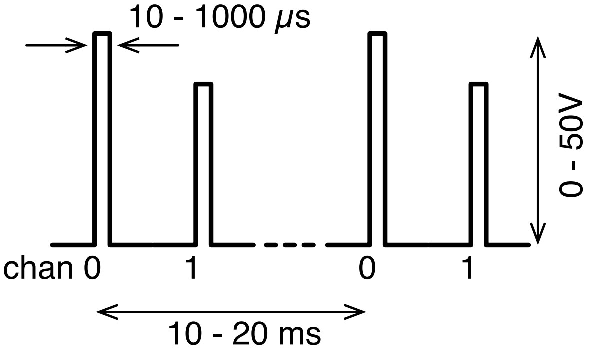

Figure 4.2: Typical multiplexed muscle stimulus pulse train.

Muscle multiplexing is a serial scheme, where a pulse train is generated and applied to a large anode electrode which is mounted on a central location on the human body, usually on the chest. The cathodes, small 5mm^2 carbon silicon electrodes, are located at the motor points of the facial muscles and are switched on/off in sync with the pulse train events. In the temporal domain, only one electrode or muscle is switched on at a time, consequently electric current only flows through one electrode. Figure 2.2 and 2.4 illustrate the physical appearance of this arrangement. Muscle intensity is solely controlled by varying the pulse amplitude.

This setup, as explained in the background chapter, provides detailed, concurrent and smooth control over the e-expressive muscles of the face, which has given rise to electro-facial choreography that is researched in this thesis. Electrodes attached to the facial surface are minimal in size and therefore offer an aesthetically appealing solution, not obscuring the

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[75] Appendix C has details on how the large ratio between pulse width and repeat frequency still provides muscle tetanus.

all important choreographed curves and furrows of the face, which in performance work is essential.

Improvements

The research has defined the number of e-expressive muscles of the face to a fixed set of 18 muscles, with the desire to add a few more (Future work section). The current device supports 16 independent channels, which in the multiplexed setup is about the maximum that can be achieved, i.e. 16 channels at 1 ms pulse width can just fit within a 20 ms repeat frequency.

The new setup, as discussed below, has a much shorter pulse width, 50 µs, that allows many more channels to be fit in the same 20 ms repeat frequency (20 ms / 50 µs = 400 or about 300 channels!)[76]. For the desired future expansion of the number of channels, the new system just adds another 8 outputs.

4.1.3.2.Accuracy of stimulus

Ideally, a facial muscle is controlled individually, affecting only the targeted muscle. As we discussed in Appendix C.4.1, indirect stimulation using surface electrodes, for practical reasons, is the only feasible method to use.

The mono-polar method that I have used so far, has worked remarkably well, providing a high level of detail in the controlled muscular contractions. The discussion in the background chapter attributed this high level of accuracy, to the tendency of the stimulating currents to flow to deeper tissue, away from the high resistance of the skin, which in effect isolates the electrode on the surface of the face.

A disadvantage of this method is that current flows between the localized cathode and the chest mounted anode, potentially leading to unintended or parasitic stimulus of undesired muscles or groups; i.e. stimulus interference.

Improvements

A bipolar setup, where two small electrodes are situated around the motor point of the muscle, in theory could increase accuracy as no other muscles than the target is stimulated. Consequently, a bipolar setup is also more safe as no current flows where it is not intended.

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[76] An inter-pulse gap is needed for a clear separation of the channels.

Bipolar also has the advantage that biphasic stimulus currents can be used, eliminating electrolysis effects.

Preliminary lab experiments with bipolar stimulation have shown to work, but has led to comfort issues, because superficial current flow, due to the relatively wide spaced electrodes, affects a larger area and for this reason has the potential to trigger more pain receptors than in mono-polar stimulus. Another disadvantage of the bipolar method is that the number of electrodes attached to the facial surface is doubled, cluttering the face, which is less attractive.

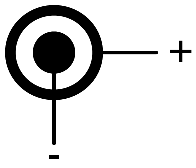

Figure 4.3: Bulls-eye electrode

For these reasons, an experiment was conducted with a small ‘bulls-eye’ electrode that was placed directly over the motor point. My lab notes mention that a stimulus amplitude of about 60 V and a pulse width of about 450 µs were needed for a full muscular contraction. However, and what is more important, it produced a significant increase in the discomfort of the stimulating impulses; a very unpleasant ‘glowing’ sensation of the skin. The wide pulse width is indicative of the experienced discomfort of the stimulus. This unfavorable effect can possibly be remedied by shortening the pulse width and biphasic stimulus, but this would require much higher amplitude levels, complicating electronic design. Bipolar and biphasic stimulus has consequently been given up upon.

4.1.3.3.Comfort

Electrical stimulation of the muscles as described in Appendix C.5.3, and as we have just seen, suffers from an inherent issue of discomfort, due to the excitation of the embedded nociceptors in the skin. This inconvenient problem can be reduced by the proper choice of the pulse width of the square wave currents; pulse widths between 10 µs and 1 ms are experienced as ‘pleasurable,’ where shorter is better.

Improvements

The current[77] device uses pulse widths of 1 ms, which is at the upper (dis)comfort range and therefore is subject to improvement. As we have seen in the muscle strength-pulse duration relationship in Appendix C.3, higher currents are needed when the pulse width shortens. In the design of the new electronic stimulus device, a balance has to be found between these two parameters to effectively stimulate the muscle. Lab experiments showed, that compared to the previous device that used a pulse amplitude of 35 V and a pulse duration of 1 ms, full muscle tetanus could be achieved with a pulse width of 50 µs and a pulse amplitude of 50 V.

Another important issue in comfort is related to the practical problem of electrode dry-out. When an electrode dries out, the conductive gel that is applied between the silicon carbon electrode and the skin, slowly decreases the effective coverage of the electrode on the skin. The contact resistance increases, leading to a decreased muscle contraction.

In electronic design this category of problem is resolved by keeping the current constant, so when, in this case, the contact area decreases, the current remains the same and hence the muscle's intensity. The result is that current density at the reduced contact area is increased, decreasing comfort. For this reason, the current and new device use constant voltage instead of constant current circuitry for the stimulation of the nerves.

Electrolysis of bodily tissue is another uncomfortable issue that is caused by the constant flow of direct currents. A direct current blocking capacitor effectively takes care of this problem.

4.1.3.4.Safety

Comfort and safety often go hand in hand, the just discussed issues of dry-out and electrolysis, have a safety component. Both, in extreme cases, can cause damage to the epidermis. The safety issue of correct placement of the electrodes on the body with regard to safe current paths is discussed in the Appendix C. This section discusses the most important safety measures that need to be incorporated in the electronic design of the facial muscle control system.

Galvanic isolation

To avoid inadvertent current paths, no current flow to and from the facial stimulus device is allowed, for this reason, thorough galvanic isolation is a prerequisite. The last generation of

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[77] No pun intended.

device, could be operated from a 9V battery, effectively separating the device from other electrical systems in the environment. Furthermore, the communications channel was built on the safe opto-isolated MIDI interface.

Improvements

The new device improves on safety by adding a wireless communications channel (Bluetooth), so no physical connection to any other appliance is necessary.

Safe current limits

A prerequisite of the safe use of electricity on the human body, is to control current levels to stay, in all conditions, within well defined limits. Safe current levels of the device were passively enforced by the current sourcing capabilities of the used electronic operational amplifier and the limited current capacity of the 9 V battery power source. A 9 V battery cannot provide enough current to cause tissue damage, although, it should be mentioned, can cause cardiac arrest when it is applied directly to the heart.

Improvements

In addition to the passive current control measures, the new device is adopting an active approach by monitoring current levels in real time. Current levels of each individual electrode are measured with the aim to keep current levels within the well defined and calibrated current limits. Dimensioning of electronic components in the current sourcing circuitry is sufficient to passively keep current levels within safe limits in case the current monitor fails to work properly.

In addition, the new device uses the proven constant voltage stimulation method, which is regarded safe and reliable.

4.1.3.5.Ease of use

Before a facial control system can be deployed in a performance, muscle onset and apex current levels need to be calibrated to the changing conditions of electrode placement and conductivity. The process of calibration has some issues that can be improved upon. The first issue is that calibration of muscle intensity level was done on a host computer, and calibration state was saved on the host system. In performance practice, the calibration host computer and the host computer controlling the performance often are not the same machine, requiring an often on stage, inconvenient and error prone manual transfer of calibration values prior to the performance. The new device stores calibration values locally on the device itself, eliminating the problem entirely.

The second calibration issue is the use of absolute voltage values instead of normalized values between 0 (off) and 100 (full intensity). The language specification that follows, designates muscle intensity as a normalized value. In addition to defining the apex of muscle contraction, it also defines a muscle onset value that allows increased ease of use of muscle control.

Electrode positioning over the motor point of a facial muscle can take advantage of the real time current monitoring facility that is part of the improved safety measures. The direct relationship between the amount of electric current and the level of muscular contraction, is indicative of accurate electrode placement. The on-device screen can be used as a visual aid in displaying the actual current level when positioning the electrode over the motor point.[78]

Calibration of muscle intensity levels has been dependent on a host computer. The new device is designed to be used standalone, doing away with the host computer requirement. A user interface consisting of a small LCD color screen and thumb wheel for manual control, allows on stage calibration.

4.1.3.6.Reliability and Portability

Previous devices have a track record proving their reliability in stage performance. The discussion above on real time current monitoring, voltage versus current control, calibration and local storage of calibration values, attribute to an increased reliability in the often unpredictable conditions on stage.

A prerequisite for stage use of a facial control system is that the device can be carried around, preferably mounted on the body in a convenient location. The current device was too bulky for this purpose, so the performer usually had to sit down with the device on its lap. It also had the requirement to be connected by a MIDI cable to a host computer. These factors impaired the use of the device in the possibly dynamic on stage context.

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[78] Depending on how such a facility is used, auditive feedback on electrode placement and current level might proof more useful.

Improvements

The new design resolves these portability issues by using a wireless communications channel, and a thorough miniaturization of the electronics by using SMT (Surface Mounted Technology). Bulky connectors were also replaced by multi-connectors merging many functions in one multifunctional port. Also the large number of electrode connectors were merged into one multi-connector, attributing to ease of use.

Appendix D.2 shows the final assembled prototype circuit board and figure 4.4 the final boxed device.

Figure 4.4: Boxed prototype showing on screen muscle state information.

Summary

Contrary to common neural-stimulus practice, the mono-polar and mono-phasic stimulus method that is used, is potentially regarded as controversial in the professional biomedical engineering practice, because of the the non-localized current paths that are potentially less safe. For this reason, biphasic and bipolar stimulus methods are professionally preferred. However, the method I developed, is very efficient, aesthetically appealing and safe, due to the hyperpolarizing effect and large size of the chest mounted anode electrode.

The facial control system as proposed and developed, is improved on safety and ease of use, by means of active monitoring of current levels. Miniaturization and wireless connectivity have made the device extremely portable; it is not larger than a regular mobile phone. Moreover, comfort of the unpleasant stimulating impulses has been improved by drastically reducing the pulse widths.

4.2.The Language of Facial E-Motion

Facial expressions have been man's first and original language long before the spoken word. In the words of Emmanuel Levinas the face is: "The language of the inaudible, the language of the unheard of, the language of the non-said." (Levinas 1998, p.199) For Walter Benjamin "Every expression of human life can be understood as a kind of language..." (Benjamin 1996, p.62) Nelson Goodman in the introduction to "Languages of Art" (Goodman 1976, p.xi,xii) immediately refutes the use of the word 'language' in the title to be replaced by a 'system of symbols,' while the Oxford dictionary's description of the word adds '..and rules.'

Human languages are constructs which are used by human beings to help them to make sense of the world and also to enable them communicate with one another. Languages usually involve a signifier, the physical form and a signified, the meaning or idea expressed by a sign. In the study of neurally induced facial displacements, the signs, refer directly to the signified, the internal state of the brain, the emotions.[79] Facial displacements can be combined and in doing so they convey different meanings. In the literature, the vast majority of facial expression research is attempting to decode the meaning of the signs, and to categorize these into systems (e.g. FACS) which was reviewed in chapter 1 of this thesis "decoding." In our research however, the face controlled by a digital computer, the face is treated purely as an abstract display device, where the 'system of symbols and rules' is greatly determined by the controlling agency, i.e. digital computation. The signs in this setup are the facial displacements signified by the abstract rules of computation.

Research done by Duchenne (a physiological grammar of the emotions), Hjortsjö (a mimic language as a vocabulary comprising letter and words forming complex expressions) and Ekman / Friesen (the comprehensive Facial Action Coding System (FACS)) is very valuable in its own right, that is the decoding of facial expression into meaning. However,

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[79] These issues are still contested in the classic nature versus nurture debate. As the research is discussing external facial control, it is less relevant for the discussion.

another area of research in the literature attempts to describe facial expression from a computational perspective. Computer animation of facial expression on three dimensional virtual models of (talking) heads, a highly developed branch of CGI[80] research, provides a higher level of abstraction, i.e. a facial parameterization from a control perspective. Despite the developed computational tools to control the face, the research in CGI is limited in that it aims to mimic natural, that is, neural facial behavior.

A comprehensive survey of research in this area was done by pioneers Frederic Parke and Keith Waters. In the book "Computer Facial Animation" they outline the most important concepts. (Parke and Waters 1996) The bulk of this research in its objective of creating natural looking and behaving faces, does not investigate the face as a site for computational expression, but works almost in reverse, trying with the help of computational tools to mimic neural facial behavior.[81] Consequently this type of research is not exploring the inherent expressive potential of the computationally controlled human face, i.e. systematic exploration of dynamic face space has been ignored.[82]

In the present thesis, the explorative facial framework or language that is designed, the *Language of Facial E-motion*, takes elements from existing research and tailors it into a formal system with the aim to describe electronic facial movement. The explorative framework abstracts out the action of a single muscle and formulates a logic that incorporates theoretical logic operations on sets of muscles with respect to the facial topology. As a language the system allows a finite set of operations on a finite set of actuators to be combined into a potentially infinite number of movement patterns.

4.2.1.Layers of Abstraction

Ideally, for the purpose of the present research an explorative system is required that is able to control every aspect of facial motion with ease. Furthermore, it is desirable to be able to tell the system with one command to perform a series of (interrelated) movements without having to deal with the underlying complexities of for instance timing or electro-stimulus

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[80] Computer Generated Imaging.

[81] Potentially this research will supplant the natural actor, news reader and weather (wo)man by computer generated characters. That will do exactly what we like, have no sick leave and will have no union.

[82] Note that aforementioned Ekman and Friesen did investigate all possible facial muscle configuration patterns, that is static face space, but not sequences of these patterns.

details. Computer facial animation researcher Prem Kalra et al. suggests a layered approach defining high *what to do* and low *how to do it* levels, five increasingly abstract levels from a single abstracted muscle action to emotions and synchronous lip sync with generative speech. (Parke and Waters 1996, p.135)

The layering that is proposed here starts at the lowest level with abstracting the action of a single muscle, aptly called the *Muscle Abstraction Layer* (MAL). It is based on HAL, the Hardware Abstraction Layer, which is an interface in between some hardware device and software. It is commonly used in computer engineering where its function is to hide the differences between various similar devices. Similarly the MAL hides the differences between the individual facial muscles so they can be handled identically. It naturally incorporates temporal aspects of muscle movement in its definition.

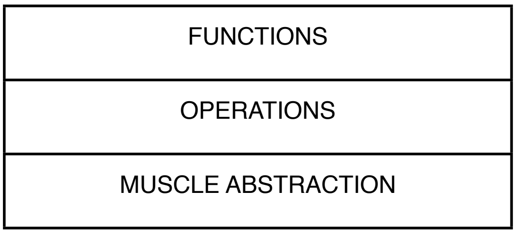

Figure 4.4: Muscle Abstraction Layers

On top of the MAL an *operational* layer defines basic theoretical operations on sets of abstracted muscles. A *functional* layer tops the layered scheme, which is the most abstract of layers that allows high level functions (words, sentences) to designate complex facial movement patterns and takes care of things like choreographic events.

4.2.2.Muscle Abstraction Layer

The muscle abstraction layer is the lowest level of abstraction and its purpose is to provide easy to use e-choreographical facial components hiding the details of electronic stimulus of the facial muscles. It defines single muscle action and determines essential choreographic parameters like muscle speed and digital muscle resolution. As a side effect of muscle speed measurements, it investigates resonance phenomena of the facial muscle under digital control.

4.2.2.1.Muscle Action

A muscle contraction manifests itself by pulling its both ends together and is a continuum from fully relaxed to fully contracted. Magnenat-Thalmann et al. describe an idealized abstract muscle action (AMA) as having a minimum, maximum and actual state of contraction. (Parke and Waters 1996, p.129)

In the artificial world of CGI these parameters correspond directly to visual component deviation, in the real world of electro-stimulus and muscle contraction, these do not correspond directly to levels of stimulus intensity. Especially the onset of a displacement has a significant threshold level of stimulus and likewise the visual apex[83] is already reached while the intensity of the stimulus can still be increased. Usually overstimulating a muscle beyond its apex is avoided as it has no advantage in response speed or otherwise and can lead to unpleasant muscle cramp. The muscle speed section that follows provides more details.

By calibrating the onset and apex of visual displacement to set stimulus levels, a muscle intensity level parameter is defined having a normalized value between 0 and 100 where 0 is no stimulus,[84] 1 the onset and 100 the maximum displacement. It conveniently abstracts away the details of electro-stimulus of the facial muscles to become an easy to use e-choreographical parameter.

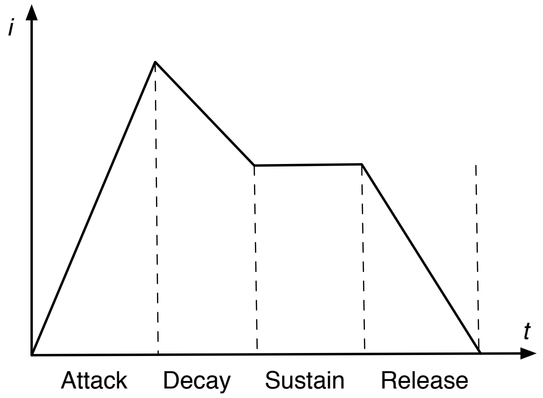

Figure 4.5: A generic ADSR envelope

Muscle contraction as a physical phenomenon, like sound, evolves over time. Figure 4.5 shows the intensity versus time relationship in a generic temporal envelope. It shows a series of events starting with the onset of a displacement to reach the apex, a fallback to a stable

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[83] Ekman and Friesen use the term *apex of an action* to describe this visual maximum deviation.

[84] For obvious reasons it is not desirable to have electrical currents running through the face while a displacement is not visible.

state, a duration and a relaxation time. Of importance are the response (attack) and relaxation (release) times as they are determined by the physical properties (mass, elasticity) of the muscle, skin and tendons. In the next section these important times are measured on real facial muscles. The measurements further show that in the real world of muscle stimulus, the decay time is redundant. (Figure 4.5)

4.2.2.2.Muscle Speed (Response and Relaxation Times)

As time is an elemental property of muscle contraction and in choreography, it is essential to know the response and relaxation times of the stimulated facial muscles. Physical properties (e.g. mass, elasticity) of the muscle and surrounding tissue play a crucial role in the time it takes for a *facial component displacement* to reach its visual apex and vice versa to return to its relaxed state. They serve as delimitations on the maximum achievable speed and therefore are important e-choreographic parameters.

The *facial component displacement speed*, which equates to a full muscular contraction, correctly denotes this temporal parameter. However in this research we simply denote this e-choreographic parameter *muscle speed*.[85]

Otto Gillert (Appendix B.3) has put a single twitch duration time for the red and white (generic) muscle fibers in the realm of 30 to 100 ms. However, a single muscle twitch doesn't equate to muscle tetanus[86] or a full muscular contraction, so how does twitch speed relate to displacement speed? Gillert provides a partial answer as muscle tetanus is achieved by the accumulation of a rapid succession of muscle twitches, about 80 twitch quanta per second are needed for maximum muscle tension.

Further a muscle twitch is a propagation phenomenon that spreads from the excitation point through the length of the muscle. From this can be deduced that a relation exists between muscle length and contraction speed, i.e. the longer the muscle the slower it will be. In addition longer muscles also have more mass and therefore are likely slower. In my research I have found no definitive answer to the muscle speed/length relationship. For the purpose of the research to provide workable data for e-facial choreography, muscle speed for the individual facial muscles is determined in the following experiment.

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[85] *Visual muscle speed* is also used to emphasize actual displacement of the individual facial components.

[86] Muscle tetanus is the prolonged contraction of a muscle caused by rapidly repeated stimuli.

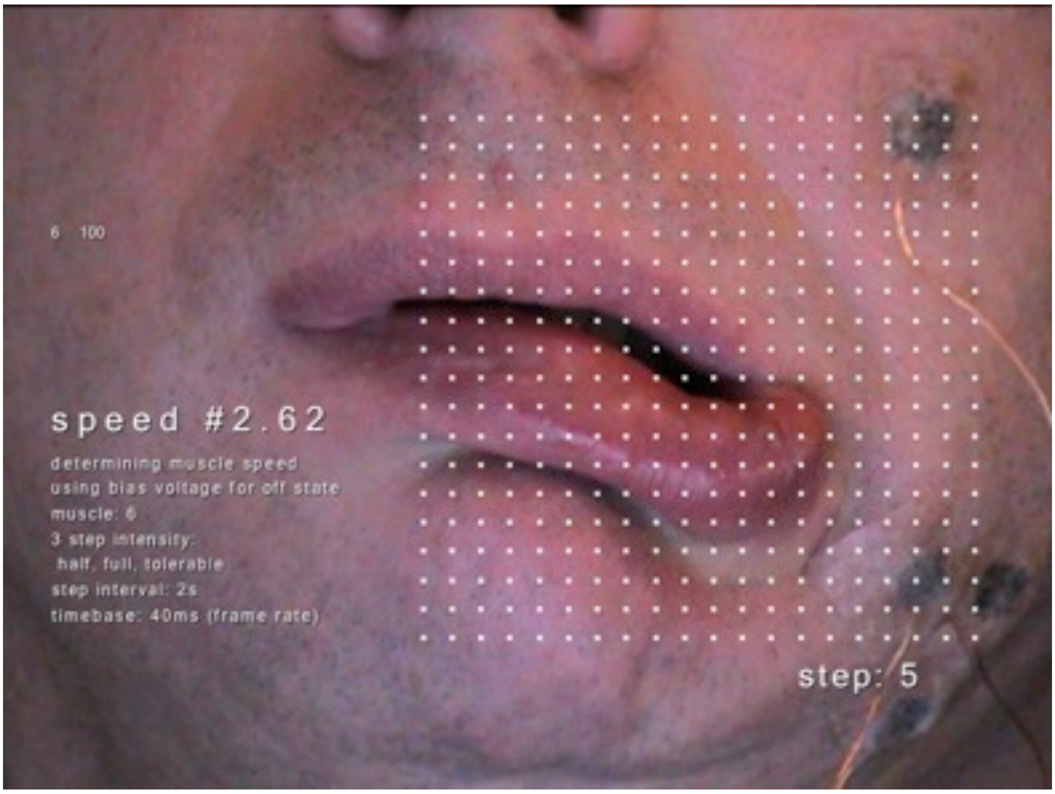

Figure 4.6: Facial Muscle Speed: video frame showing a full displacement. (Note: grid used as a visual aid in head framing.)

Measuring facial muscle speed

Facial muscle speed is measured by observation of visually annotated video recorded muscle contractions.(Figure 4.6) The accuracy of the measurement is delimited by the video frame rate of 25fps (40 ms/frame) which is rather poor in relation to the muscle twitch speed. A high speed camera could have generated more accurate results, but has not been used because in this art application we are more concerned with qualitative effects than with obtaining numerical results. Each experiment has been conducted three times and the results averaged (mean) to level out one off frame rate errors and other anomalies.

The experiment measures the temporal properties of the stimulated muscle: the response and relaxation speed. It further tests if bias and overshoot stimulus levels affects the contraction speed. The experiment has been conducted with three stimulus levels:

1. half — stimulus level is calibrated on half the apex of visual displacement,
2. full — stimulus level is calibrated on the visual apex of the displacement,
3. overshoot — stimulus level is calibrated beyond the visual apex of the displacement at a stimulus level that is tolerable to the subject without causing muscle cramp, i.e. just below the (subjective) pain level.

These three stages are repeated in successive measurements with a bias stimulus level that is calibrated on the onset of displacement. This is done to determine if bias has an affect on muscle speed.

Results

The following table shows average tabular data on the observed response and relaxation times of (un)biased stimulated facial muscles. The times were obtained by counting video frames indicated by on and off stimulus events superimposed on the live video recording. Complete tabular data is provided in Appendix F.

		no bias		**bias**	
	Stimulus Level	**On (ms)**	**Off (ms)**	**On (ms)**	**Off (ms)**
averages (mean)	half	510	484	600	598
	full	385	499	501	594
	overshoot	423	502	520	560

Table 4.1: Average (mean) response and relaxation times of stimulated facial muscles.

Bias(-slow) effect

Averages for the no bias experiments show response times around 400 ms and relaxation times around 500 ms and for the bias variation 500 and 600 ms respectively. This data shows that applying a bias stimulus level is roughly 20 to 25 percent slower than without a bias. An explanation for this behavior might lie in impulse behavior of the stimulated muscle, where a bias dampens its responsiveness. This bias-slow effect works both ways, response and relaxation times are affected. The bias-slow effect is of importance for facial choreography and the design of facial stimulus devices because concurrent current flow through the face could increase bias current levels and for this reason reduce facial muscle response times.

Overshoot effect

Taken up on the above reasoning, one would expect the overshoot measurements to show an *increase* in speed over the full stimulus, but on the contrary the response measurements show a slight *decrease* in response time. The reseating of the muscle in its relaxed state however is not affected by bias. In this case it seems the muscles have become saturated above a certain stimulus level, another cause is perhaps the viscoelastic properties of the muscle and surrounding tissue, but no conclusive answer is sought after. It should be noted that the speed decrease is marginal and that the cause of this effect is not relevant for the research. Because overshoot has a negligible beneficial effect on muscle response, the decay stage of the muscle's temporal envelope can be omitted.

Displacement-time relationship [87]

Analysis of the tabular results data reveals speed differences between particular facial components. A comparison between experiment 1.2.x and experiment 1.6.x for example shows the lowering of the brow to be much faster at 307 ms than the 400 ms for the depression of the lower lip. A further observation is the distance each comparative component has to travel to reach its apex. Drawn from these observations a logical relationship between displacement distance and time exist, a typical space-time relationship.

To more accurately define a facial component displacement (in milimeter) per millisecond relationship, a new experiment is needed that measures absolute displacement of facial components over time. Such an experiment needs a much better temporal resolution of the recording medium, i.e. high frame rate video and a very stable head fixation.

Conclusion

If responsiveness is a key factor in an e-facial choreography piece, it is beneficial to calibrate maximum stimulus level directly onto the apex. Unless slowly moving facial components are needed, one will mostly use maximum stimulus levels. Overshoot stimulus levels have a detrimental effect on muscle speed. Consequently the decay stage of the temporal envelope of a single muscle action can be omitted.

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[87] Muscle length/speed relationship.

4.2.2.3.Muscle Resonance

Measuring and analyzing muscle speed and the muscle’s physical properties, raises the question if facial muscles can have a resonance state. Resonance is an important physical phenomenon, its electrical manifestation is the basis for radio and television, and its mechanical instance the basis of most musical instruments. Every physical body has a particular resonance frequency (eigen-frequency), which depends on its shape, size, mass and elasticity. Likewise the intrinsic mechanical properties of the facial muscular system consisting of muscle tissue, elastic and viscoelastic properties of the skin and the bone connecting tendons determine the muscle’s eigen-frequency.

Parke and Waters describe the mechanical properties of the skin-muscle-tendon construct, a biological solid, as a combination of an elastic solid and a viscous fluid. This combination can be expressed by Hookean and Newtonian laws respectively, which in essence describes muscular behavior as a tunable spring. (Parke and Waters 1996, p.226) [88]

Attributing to facial resonance, is the typical facial structure where muscles have no clear antagonist. The protagonist contraction is not counteracted upon, it is not (strongly) damped and therefore behaves much like a one sided attached spring.

Electric Eigen-Portraits: a facial muscle resonance experiment

In a nonscientific, artistic experiment eight facial muscles are subjected to a simple on/off stimulation pattern, with a repetition period that varies gradually between 2 seconds and 100 milliseconds. It shows the human facial display in a state of externally triggered resonance.

At fast stimulation rates, the external input looses its precise control of the muscle contractions: resonance patterns appear which are primarily determined by the intrinsic mechanical viscoelastic properties of the facial muscle system. The face thus displays its own mechanical properties on the face itself. A self-portrait of the face, manifested by its eigen-frequencies: an "Eigen-Portrait."

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[88] For the e-facial choreograph it is of interest to know that elasticity of the skin and muscles changes with age due to a reversal in ratio between elastin and collagen. These are two cellular tissues responsible for elasticity, where elastin behaves much like an ideal rubber, found mostly in the skin and collagen, responsible for the elasticity of the tendons to be much more stiff. At younger age the skin has a large ratio of collagen while at an older age it contains more elastin. In terms of skin, older equals more flexible. See also Elhers-Danlos Syndrome as exemplified by Garry Turner in the section on facial exploration.

Figure 4.7: Electric Eigen-Portraits: facial muscle resonance phenomenon. Videography: Josephine Jasperse and Jeroen Meijer

The experiment had a programming flaw where the fastest on/off stimulation pattern was unintentionally delimited to 100 ms. Despite that flaw and deduced from the observed resonance phenomena the facial muscle eigen-frequency can be set to about 100 ms (10 Hz) which is close to or at the muscle's twitch speed.

The accompanying DVD shows the full "Electric Eigen-Portraits" video.

4.2.2.4.Muscle Resolution

Muscle contraction is an analogue phenomenon spanning a continuum from fully relaxed to fully contracted that we already have defined as a normalized facial component displacement level between a minimum and a maximum. To express a continuum in a digital control system is inherently impossible and for this reason continua are expressed in enough discrete steps such that they are perceived as a continuum. An example from daily experience is digital music in which the *resolution* of digitally encoded sound, is just high enough so it is perceived as continuous sound waves.

Likewise controlling facial muscles by digital means requires sufficient discrete steps to define a smooth muscular contraction. For this reason *muscle resolution*[89] is an important e-facial choreographic parameter. The following experiment measures this parameter for the individual electro-expressive facial muscles.

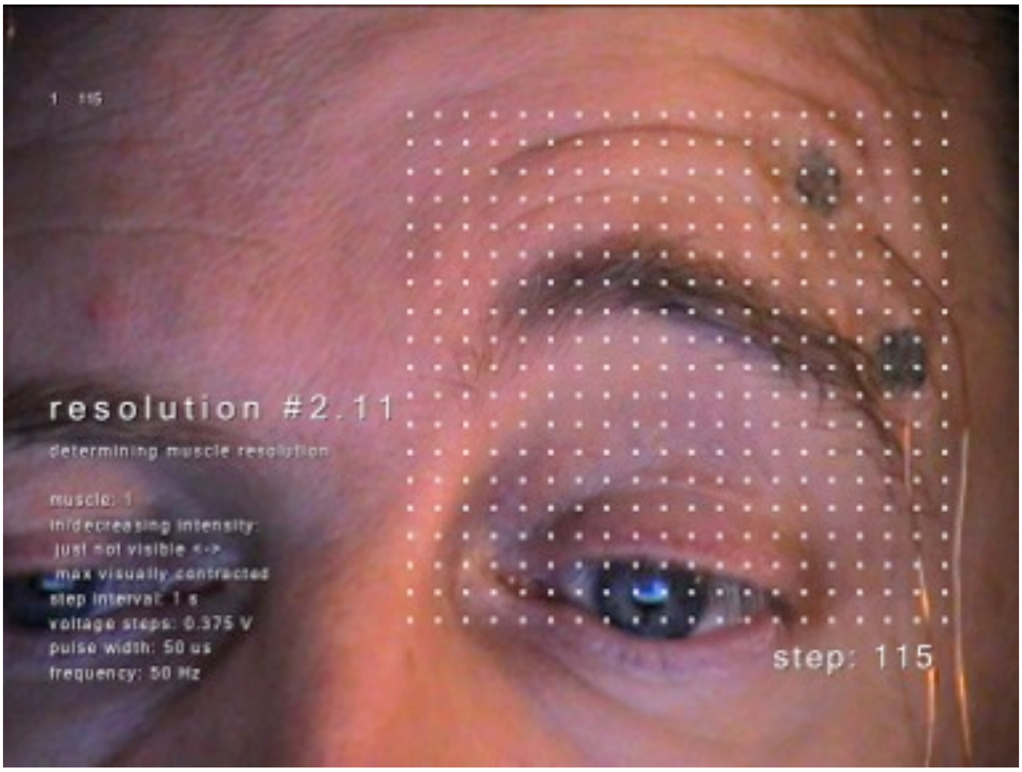

Figure 4.8: Muscle resolution: determining minimal perceptible steps.

Measuring muscle resolution

Measuring the minimum number of steps needed for a full facial component displacement, is based on the concept of minimal perceptible action or as Ernst Heinrich Weber (1795-1878) formulated *just-noticeable difference* (JND). (Stevens 1986, p.182) What is now known as Weber's law, is a rather simple method, it relates an increase in stimulus of some sort to a just noticeable change or difference.

Observing gradual changes in stimulus levels and the resultant facial component displacements is done by means of annotated video recordings of the electro-expressive muscles on one side of the face. (Figure 4.8) A change in component displacement is then noted against the stimulus level. To eliminate inaccuracies and anomalies, the experiments

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[89] *Digital muscle resolution* would perhaps be a better designation for this parameter, but again simplicity is decisive.

were repeated three times. For completeness the opposite direction, a decrease in stimulus steps were recorded as well.

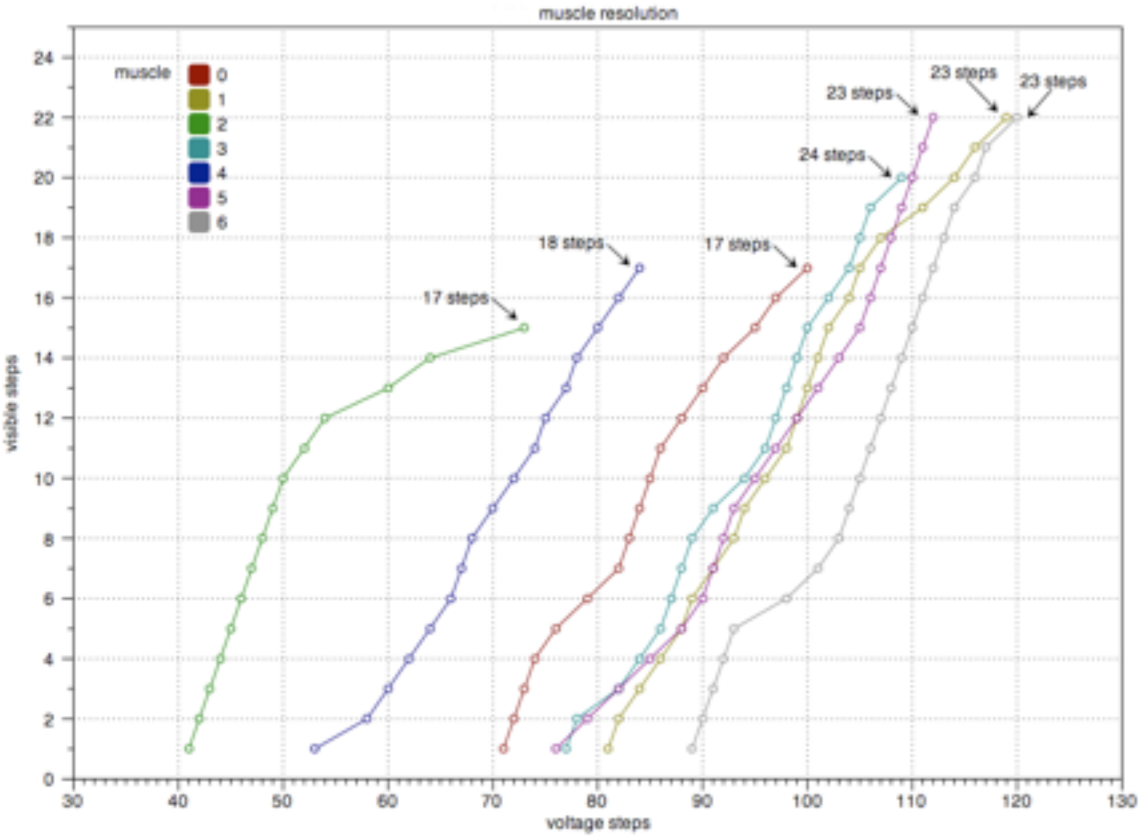

Figure 4.9: Muscle resolution. (0.375v/step)

Results

The above graph shows the relation voltage steps and observed visible displacement steps based on average (mean) JND data. The graph clearly shows the onset of displacement in discrete stimulus levels can vary quite a bit amongst the different muscles, the reason onset stimulus levels have to be calibrated. It further reveals that a relatively small number of discreet steps are needed to describe a smooth movement from the onset to the apex of displacement; just 17 to 24 steps.

As in the muscle speed measurements, the amount of component displacement plays a crucial role. We again compare muscle 2 and 6 having a resolution of 17 and 23 respectively, it conclusively shows the larger the displacement the more steps are needed.

We further note a shortcoming in how the measurements were conducted. In some instances each successive increase in stimulus did result in a visible change with no room for imperceptible steps. A prerequisite for a JND experiment is that the granularity of stimulus needs to be higher than the perceived sensation. This observation has prompted a redesign of the stimulus electronics controller software. In preliminary design a stimulus level of 0 was simply mapped onto an output voltage of zero and 100 to the maximum output voltage allowed, which resulted in a rather coarse granularity.[90] In software a scaling was implemented in such a way that the full intensity range from 1 to 100, directly maps onto the effective range, the onset and apex of the stimulated contraction.[91] This effectively increased the available stimulus resolution by a factor of three, but no experiments with the new software have been conducted. The main objective to determine muscle resolution was to find out if the available resolution of the controlling hardware would be sufficient for smooth control. As we have seen, a normalization in the range of 0 to 100 has enough room for subtle muscle control.

We can however safely assume that in the plotted curve where each stimulus step directly caused a visible displacement, the granularity of stimulus at least has to be doubled. When we do this the muscle resolution for the electro-expressive muscles increases to fall within the 22 to 39 range. Mapping muscle resolution onto the available stimulus resolution therefore is sufficient for smooth digital control with enough room for subtleness.

Lastly we note that for a biological entity the plotted curves for most stimulated muscles are surprisingly linear. From an e-choreographic control perspective linearity is very convenient because it represents a direct relation between a numerical and facial element displacement.

Summary

The Muscle Abstraction Layer defines muscle properties and behavior as the following e-choreographic parameters:

- **Muscle Intensity or Level** — a value denoting the continuum from the onset of visual displacement to its visual apex. Default value normalized between minimum 0 and maximum 100, where 1 represents the onset of displacement.

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[90] Note: the graph shows actual stimulus voltage levels, not normalized values.

[91] Zero intensity level represents absolute zero voltage or no stimulus, 1 maps onto the onset.

- **Muscle Resolution** — a value denoting the minimum number of discrete steps needed to describe a smooth digital controlled contraction of the individual electro-expressive facial muscles. Default value between 22 and 39 discreet steps.
- **Muscle Speed** — a value denoting the time needed for a facial component to reach the visual apex from a relaxed state. Default value 400 ms response and 500 ms relaxation time on average.
- **Muscle Resonance** — a value denoting the eigen-frequency of a facial muscle. Default value approximately 100 ms (10 Hz).
- **Muscle Duration** — a value denoting the duration of a muscle contraction. The temporal muscle envelope naturally incorporates the response and relaxation time. Default value the sum of response, duration and relaxation times.

4.2.3.Operational Layer: Fundamental Set Operations

When we refer back to the introduction of this thesis, the Swedish anatomist Hjortsjö's notion that the human face is an orchestrated instrument playing a melody, *orchestration* of the facial muscles obviously is key to facial choreography.

To draw on the musical analogy, a single note doesn't make a chord or melody and likewise muscular contractions need to be combined to create compelling facial chords and melodies. This is where the operational layer comes into play, it describes the finite set of logical operations on unary and binary sets of muscles. These theoretical operations on muscle sets are then put into the context of the facial topology; a *topological* grouping.

4.2.3.1.Unary (One) Set Operations

Sets of elements, muscles or something else, can be altered according to a finite set of rules or logical operations. When we consider a set of elements that can either have an on or off state, illustrated in figure 4.9, a few rules can alter the on/off pattern. The simplest operation is to invert each element's state, the *inverse* or in Boolean logic the *NOT* operation.[92]

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[92] A little exercise to show why e-facial choreography matters, try pulling a *NOT face*...

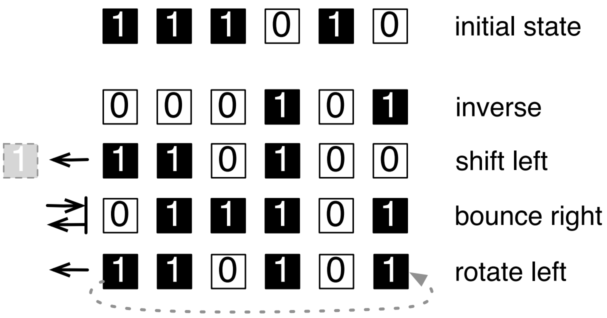

Figure 4.9: Unary set operators.

Moreover element state can be manipulated by two similar *move* operations: *shift* and *rotate* with a directionality of *left* or *right*. The difference between both variations is that rotate wraps around a shifted out element and moves it back in on the other end, while shift moves the element into the void. Repeated use of the shift operation therefore yields the set empty. A variation on the shift operation preserving state is the *bounce* operation,[93] it reverses the direction of the move when a specified element hits an extreme. The unary set operators bounce and rotate preserve the on/off state pattern and consequently are mostly used in e-facial choreography.

4.2.3.2.Binary (Two) Set Operations

The unary operation targets a single set of elements, the binary operation targets two sets. The number of binary set operations are again finite and come in two varieties. The one variety are the Boolean logic operations AND, OR and XOR and the mathematical operations addition, subtraction, multiplication, and division. They work on two sets of elements and yield another set holding the result, which for this reason requires a mapping definition.

Boolean and mathematical operations on the facial muscles effectively turn the human facial display into a kind of Boolean abacus. While it might give new meaning to the notion of Boolean expressions, the mapping definition requirement severely limits its usefulness for e-facial choreography.

More useful binary operations not requiring a results mapping are the *swap* and *complement* operations. Swap takes one elemental set and exchanges its state with another, same sized, set. Often this operation is referred to as the *flip* when it is applied over for

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[93] In animation this auto-reversing operation is often called *ping-pong*.

example an axis. The next sections show the flip operator to be a powerful e-choreographic operator.

The concluding binary operator is *complement*, it works by simply copying element state from one same sized set to another, so the sets become identical. Complement is an operator that yields facial mirror symmetry when it is applied over the vertical axis.

Summary

The Operational Layer describes the fundamental unary and binary operations on sets of elements:

Unary operators (involving one set)

- *inverse*
- *shift*
- *rotate*
- *bounce*

note: the three move operations require an, initial in the case of the bounce, directionality.

Binary operators (involving two sets)

results mapping required:

- mathematical *addition, subtraction, multiplication, and division*
- Boolean *AND*, *OR*, *XOR*

no results mapping required:

- *flip*
- *complement*

In e-facial choreography set operations are not applied to abstracted elements, but are the physical muscles arranged in the characteristic structure of the face. The next section discusses the strategic grouping of the muscles in accord with the topology of the face. Topological muscle grouping facilitates an effective exploration of dynamic face space.

4.3.Topological Set Operations: The Choreologic of the E-Face

Considering the dissection of the face into its topological components as we have done in the previous chapter and the logic of set operations just discussed, both logics can be combined into a new logic. The *choreologic* of the e-face that is defined maps logical muscle set operations onto their natural topological counterpart.

It is where the previously discussed results-oriented method of hacking comes into play that we called *choreologic probing*, and its purpose is twofold. Firstly, mapping both logics onto each other inherently narrows down dynamic face space, i.e. limits the possible movement patterns to a confined space. Secondly, the mapping of logical set operations onto distinct topological structures, will likely yield clearly defined and fundamental e-choreographic movement patterns that the research attempts to uncover. The language deployment section that follows shows compelling results in support of this explorative probing method.

Let us examine the topological grouping of facial muscles in relation to set operations. Figure 3.2 brings back the topological elements from the Decoding chapter, it illustrates the salient attractors and regional division into the lateral right/left and upper/lower face. Each of the attractors have a number of muscles around them deforming the facial shape. These localized muscles naturally can be grouped into a set or combined into larger composite groups for example spanning both eye attractors. Unary one set operations, the inverse and move operators, can be applied to these topological defined sets yielding movements revolving around those points.

The illustration in figure 4.10 shows the move operators including their directionality that are applied to attractor defined sets of muscles. Note that these simple operations for instance a rotate operation around the nose attractor also yields diagonal movements by proper designation of muscles in the set.

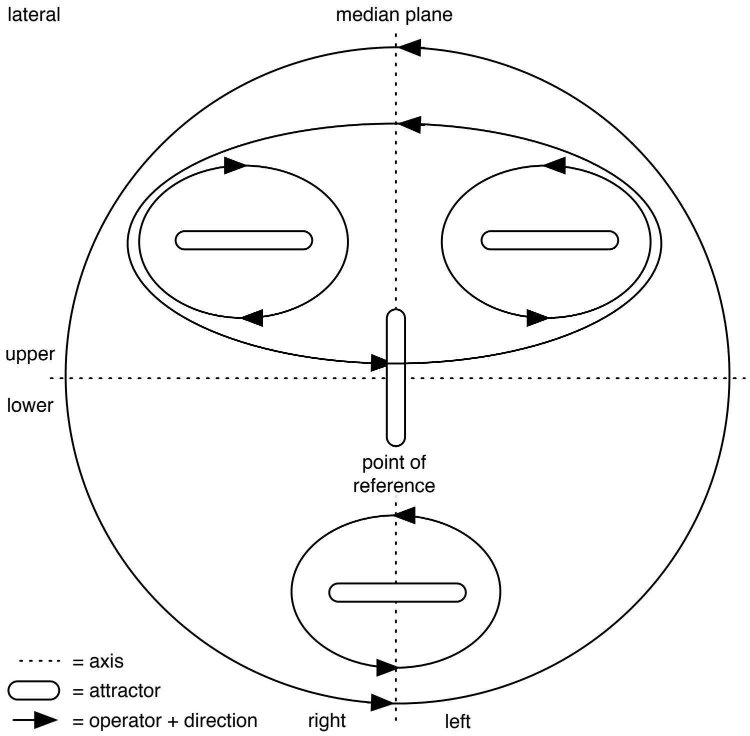

Figure 4.10: Topological set operations: the choreologic of the e-face.

The binary two set operations flip and complement can be applied to a random set of muscles across the face yielding another random set. However from a choreographic viewpoint mapping the two sets onto different topological regions of the face will produce results that are more clearly structured.

When we for example flip a lateral muscle set around the vertical axis, it creates a play on the pronounced left/right symmetry of the face producing a distinct choreographic movement. Likewise a complement operation over the same axis will yield lateral mirror symmetry in the face. The binary operator sets can also be mapped at either side of the other topological line of division, the horizontal axis, but due to a lack of mirror symmetry between the upper and lower face requires a mapping definition. Nevertheless binary operations over the horizontal axis can produce conspicuous results when the sets are chosen with directionality and proportional change of the facial surface in mind. (See Decoding chapter.)

Directionalities of the unary move operations can directly be related to lateral and medial directed movements or to the upward and downward movement of the facial elements depending on the topological orientation of the muscle set.

Summary

These are the *basic choreologic set operations* that are used extensively in the systematic probing of the face:

unary	*inverse*, *shift, rotate, bounce* + lateral/medial and up/downward directionality Applied to (combinations of) attractors.
binary	*flip, complement* Applied over the vertical and horizontal axes, lateral left/right and upper/lower face, where the latter requires a mapping definition.

4.4. High Level Functions

In the proposed layered scheme of facial movement, the functional layer is the most abstract. It allows complex facial movement patterns to be described with a single word or statement.

If for example we define an e-choreographic statement *morph*,[94] which takes three arguments representing two facial muscles and a duration, with this single statement a cross fade takes place between the two affected muscles. All the lower level operations of repeatedly changing muscle intensities and so on is conveniently abstracted away . An important statement is the empty word, the definition of facial non-activity, the so-called *blank face*.

In the research however higher level functions are not defined, because we are primarily interested in the fundamental e-choreographic movement patterns that can be deduced from probing the face with choreologic operations. It can of course be argued that the choreologic operations themselves are functions of a lower level, but that is more a matter of definition.

The next section reformulates the abstracted layering and the choreologic operations as an explorative language specification.

4.5. Language Overview

The section specifies the salient language elements of the Language of Facial E-motion. It does not strive for formal linguistic correctness as this is beyond the scope of this artistic

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[94] The use of the word *morph* here should not be confused with morphemes in linguistics.

research. It does however aim to strike a balance between the immediate practical applicability of the language within the present study and the potential for future development and implementation within other areas of application.

Constants

lateralities: left and right

directions: leftward and rightward (up/downward can be omitted as it depends on facial set orientation) lateral/medial

axes: horizontal and vertical

attractors: eyes, mouth and nose

Muscle-identifier

mi (*n* [,*lat*]) where *n* is an integer denoting a muscle and *lat* an optional laterality.

Muscle-set

ms (mi_1, ..,mi_n) where *n* is an integer denoting a muscle and *lat* a laterality.

at (ms_1 [,.. ms_n]) denotes a predefined attractor muscle set or optional combinations thereof.

Choreologic operators

inverse (*at*) where *at* denotes an attractor. Inverts muscle state in the set.

shift (*at, dir*) where *at* denotes an attractor and *dir* the direction of movement. Maps a muscle set onto the next muscle in the set with a directionality of left or right. The last muscle maps onto the void.

rotate (*at, dir*) where *at* denotes an attractor and *dir* the direction of movement. Maps a muscle set onto the next muscle in the set with a directionality of left or right. The last or first muscle in the set, depending on initial direction, wraps around to the opposite position in the set.

bounce (*at, dir*) where *at* denotes an attractor and *dir* the direction of movement. Maps a muscle set onto the next muscle in the set with a directionality of left or right. The last muscle with a positive on state hitting an extreme reverses the direction.

flip (*ms* [,*ax*]) where *ms* denotes a muscle-set and *ax* an optional axis. Flips a muscle set around a horizontal or vertical axis. When *ax* is horizontal it requires a mapping definition.

complement (*ms* [,*ax*]) where *ms* denotes a muscle-set and *ax* an optional axis. Maps a muscle set onto its complement set. When *ax* is horizontal it requires a mapping definition.

Note: when attractor muscle sets are replaced by generic muscle sets, the set operations become universally applicable yielding any possible facial movement patterns. Likewise the flip and complement operators can be made generic by removing the axis requirement.

Events

muscle-action (*mi, attack, sustain, release, intensity*) where *mi* is a muscle-identifier, the sum of *attack*, *sustain* and *release* is the duration of a muscle-action event in milliseconds. *Intensity* denotes the normalized level of contraction between minimum 0 and maximum 100, where 1 represents the onset of displacement.

Note: attack and release times can be omitted where they default on the minimum response and relaxation times as determined in the muscle speed measurement. Sustain in this case equals total muscle action or duration.

muscle-idle (*mi, duration*) where *mi* is a muscle-identifier, *duration* a muscle rest event.

Note: sequencing muscle-action events requires an idle event to introduce pauses.

Muscle parameters

muscle intensity or level — a value denoting the continuum from the onset of visual displacement to its visual apex. Default value normalized between minimum 0 and maximum 100, where 1 represents the onset of displacement.

muscle resolution — a value denoting the minimum number of discrete steps needed to describe a smooth digitally controlled contraction of the individual electro-expressive facial muscles. Default value between 22 and 39 discreet steps.

muscle speed — a value denoting the time needed for a facial component to reach the visual apex from a relaxed state and vice versa to settle back into its relaxed state. Default value 400 ms response and 500 ms relaxation time on average.

muscle resonance — a value denoting the eigen-frequency of a facial muscle. Default value about 100 ms (10 Hz).

muscle duration — a value denoting the duration of a muscle contraction. The temporal muscle envelope naturally incorporates the response and relaxation time. Default value the sum of response, duration and relaxation times.

Note: muscle duration has been incorporated in the muscle-action event.

Now that we have defined the salient features of an explorative facial language, we can put the language to good work in the next section.

4.6.Language Deployment: Systematic Exploration

"not by words, but by deeds are the arts proven." Perrin[95]

The effort made in this research, the design of the facial muscle stimulus device and the definition of the Language of Facial E-motion, facilitates the exploration of the purported untapped expressive potential of the e-face. With the conceptual and practical tools at our disposal the face is systematically probed in order to determine the unique e-choreographic movement patterns of the e-face.

Systematic exploration of dynamic face space can be done in a number of ways, where permutation[96] and enumeration[97] are the two most extensive methods available yielding a complete mapping. As such these two methods generate an enormous amount of possible facial movement patterns, too large (infinite) to go about in a practical manner. It would take forever to explore an infinite set of possible facial patterns, which is to say that such an

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[95] In advertisements for his experiments with electricity, the 18th century experimental physicist Perrin attributed this to an unnamed classical source. (Lynn 2006, p.32)

[96] As explained by Brian Eno in interview on BBC radio. Permutation as explained by Brian Eno in relation to The Long Now project, is a classic method in English church bell ringing, so all possible bell combinations are produced.

[97] In the Decoding chapter we discussed the work "The Varieties of Human Facial Expression" as an example of enumerating static face space.

extensive probing exercise has the risk of turning the experiment into a classic endurance performance art piece.

Choreologic probing

For these reasons another method has been proposed which is based on a merger of the two logics involved, i.e. the topological quality of the face and the logic of muscle set operations; the earlier formulated choreologic of the e-face. Choreologic probing excludes numerous muscle combinations and therefore inherently confines dynamic face space to a more focussed and manageable size while at the same time enhancing the likelihood of unearthing clearly defined e-choreographic movement patterns.

In practice this means the face is systematically probed by deploying choreologic operations as defined in the language; unary operations on the attractors and binary operations around the axes. Different on/off patterns have been assigned on the attractor involved muscles, mostly between four and six muscles and unary operations applied. As in the muscle speed and resolution measurements, results of the probing effort are recorded on video.

The next chapter evaluates the individual recorded probes and categorizes them into a binomial designation of fundamental e-facial choreographic movement patterns.

Artistic language deployments

The face is further explored in artistic e-facial choreography experiments. For example the pronounced lateral mirror symmetry of the face is exploited in a piece called "Face Shift." Both sides of the face are controlled by identical algorithms generating movement patterns. The piece starts with symmetric movements on both sides of the face, but as one algorithm is executed slightly faster, over time visual shifting patterns are created from symmetry to asymmetry. Two DECtalk voice synthesis machines are deployed for each side of the face, calling out the identification numbers of the activated muscles. Phonetic sounds emanating from the left and right speakers acoustically merge into newly perceived but non-existent utterances.[98]

The other e-choreography piece is called “Morphology.” As the name implies it takes a random set of activated muscles and slowly cross fades to a newly random selected set of muscles. Over time the morphing rate is increased creating an amorphous changing facial surface. So far morphology is the only experiment done with varying muscle intensity levels.

“Face Shift” and “Morphology” are available on the accompanying DVD, as is the aforementioned piece “Electric Eigen-Portraits.”

Summary

These last sections of this Encoding chapter presented a culmination of the preceding discussion in the form of a language specification. The Language of Facial E-motion defined constants, muscle identifiers, choreologic operators, events and muscle parameters. Choreologic probes as defined in the language have then been deployed in systematic experiments. These probes into dynamic face space are evaluated in the next chapter.

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[98] The piece is reminiscent to classic tape loop experiments, for instance the famed Steve Reich piece “Come Out.”

Chapter 5

5.Recoding: The New Expressiveness of the Human Facial Display

5.1.Introduction: Organized Human Movement

When we think of choreography we usually think of dance. Choreography literally means “dance-writing” from the Greek words "χορεία" (circular dance) and "γραφή" (writing). Also known as "dance composition," choreography is the art of making structures in which movement occurs.[99] The term composition may also refer to the navigation or connection of these movement structures. The resulting movement structure may also be referred to as the choreography.

Essentially, choreography is organized human movement. Hjortsjö used the word orchestration for organizing or arranging facial expressions for a desired effect which in the context of the orchestrator, the brain playing a melody, was a fitting choice of word. In this research however we prefer to use the word choreography, because it is bound to the dance of the facial features and not so much to music.

The term choreography is used in a wider context than human movement and the notation of sequences of movement. In robotics, for example, or by the Australian artist Stelarc, who uses the term to describe the movement of his technology driven body, a merger between robotics and the human body. NASA, the American space agency, employs orbiting choreographers on board the International Space Station (ISS) that is currently being built. In Extravehicular Activity (EVA) popularly known as the space walk, NASA uses the term choreography to describe the heavily scripted step by step instructions the spacewalker needs

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[99] http://en.wikipedia.org/wiki/Choreography (06-11-2010)

to undertake. On board the ISS the operator maneuvering the robotic arm that has the spacewalker mounted onto its end, is called a choreographer.[100] [101]

The definition of choreography can be extended to any structured movement whether this is human, robotic or otherwise. The term choreography is relatively young, first appearing in the 1950s. About two decades before, Rudolf von Laban and later Rudolf Benesh started to work on systems for dance notation. They were interested in dance movement notation with the aim of making dance reproducible, doing what the musical score did for music.

The systems von Laban and Benesh developed were designed from an ontological viewpoint; putting the dancer centre stage and works from the experience of the dancer. Von Laban, a dancer himself, based the system on notions like *effort* to emphasize how to reproduce certain moves concerning issues like balance and three dimensional space. In the present research, Electro-facial choreography deals with the face as a malleable surface and consequently has no concern with space, gravity, balance or effort.[102] Both Labanotation and Benesh notation are evolving systems that over time have been refined and both now have substantial libraries describing a large variety of dance moves.

However, my electro-facial choreography research method almost works in reverse, designing rule based systems that will produce often unforeseen facial movements. As such its approach is diametrically opposed to existing human movement notation systems, although it shares observation to identify and designate (symbolize) distinct movements. The next section evaluates and names the choreologically-induced facial movements in a binomial scheme that is designed for this purpose. It also introduces a limited facial *Muscle Matrix Notation* system to aid in describing and visualizing movement patterns.

5.2. Evaluation of Experiments: An Electro-Facial Choreographic Nomenclature

The “Raw Lab” videos show some compelling examples of choreologic probes into dynamic face space, a deployment of the language of facial e-motion. Without going through the vast

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[100] http://www.nasa.gov/mission_pages/station/expeditions/expedition16/journal_peggy_whitson_3.html

[101] As a side note, watching the live video stream from the ISS, has shown a new hilarious kind of performance art; the disengaging of the space suit in zero-g. It has great resemblance to the video work of renown Dutch artist Arnout Mik.

[102] In this research we are not interested in the person behind the face, we merely use its fantastic facial hardware.

amount of gathered data, the video examples are discussed and named in a loosely defined binomial scheme mostly reflecting a facial feature and an operator or observed movement. A strict choreologic designation is not feasible because a choreologic operation on a given muscle set state does not always translate directly into an observed and obvious movement pattern. Moreover different operators and proper muscle set state patterns can produce the exact same result. For example, a rotation around the mouth attractor and a flip operation around the vertical axis with the same alternating state pattern both result in the same movement pattern. As we will see this effect mostly comes about due to the symmetry of a state pattern and choreologic operation.

For these reasons and because of a lack of existing research in facial choreography, the proper designation of e-facial movement patterns as observed in this research, turns out to be a challenging task. Despite the overwhelming choice of words the English language provides in describing movement and physical states, the research had to resort to the perhaps twisted logic of observation and artistic designation.

Evaluating Choreologic Probes

The Encoding chapter discussed the conduct of the choreologic probes. What follows is the annotated naming of observed movement patterns that have a direct relationship between the choreologic operation and the observed movement pattern. These clearly defined patterns are then followed by more ‘arcane’ or difficult to name e-choreographic patterns, that often affect more muscles and/or attractors. Additionally, e-choreographic patterns are described that are the result from deduction of previous observed movements or logics.

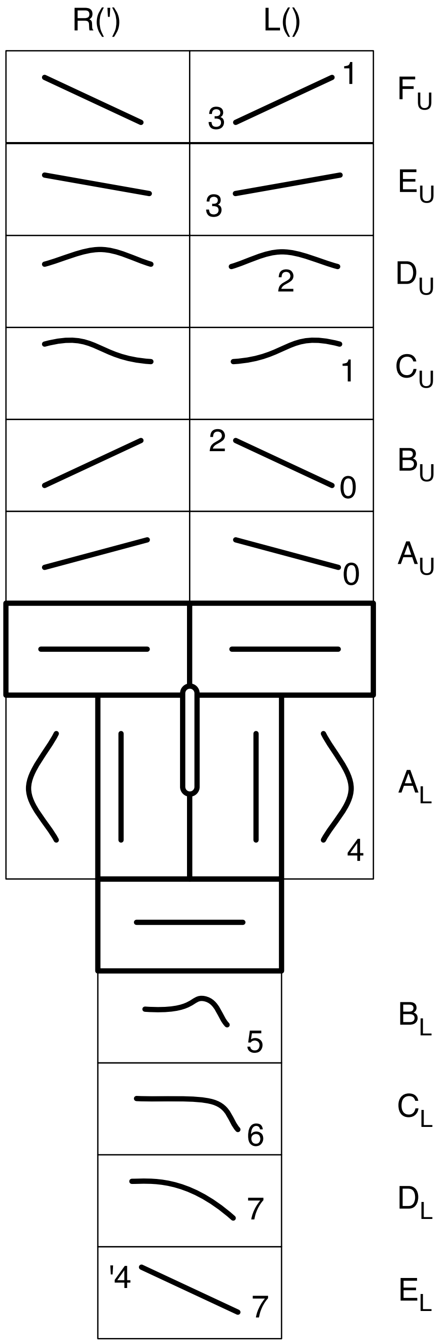

Figure 5.1: Muscle Matrix Notation, “totem pole” showing the most important e-facial choreographic elements.

n = e-expressive muscle identifier
U = upper face   L = lower face
’ = complement   (i.e. right side)
+ = and   **I** = or
→ = state change
_ or **0** = inactive state

Muscle Matrix Notation — To ease the understanding of muscle state patterns, their rendition on the face and to aid in the description of movements, an e-facial choreographic or muscle matrix notation is introduced that builds onto the left/right and upper/lower facial topology. The bold outlined mid section of the “totem pole” in figure 5.1 shows the blank or inactive face as the reference. The numbers in the diagram refer to the electro-expressive muscles. (Figure 3.5 in the Decoding chapter shows the e-expressive muscles with additional details on muscle pull, Appendix E.4 provides tabular data.) The matrix is designed with expansion in mind, so new patterns (attractor muscle permutations) can be easily added (stacked). A flip operation around the vertical axis involving the brow for example is described as D_U → ’D_U, where → denotes a state change towards another element.[103]

Blank — the inactive face, all e-expressive muscles at rest. It serves as the reference for facial movement.

Muscles: all e-expressive muscles.

Muscle Matrix: 0

Naming variant: *botox* for a completely inanimate face.

Video: many

Lip flip, brow flip **and** ***joy flip*** — a flip operation around the vertical axis that involves two complementary, that is the mirror symmetrical

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[103] The muscle matrix is not intended to be a functionally complete notation system, because muscle duration (timing) for example, cannot easily be described. Instead it is meant to be a practical aid to exploration and performance.

equivalent muscles, one on either side of the median plane. In muscle matrix notation, the complement of a muscle set is prefixed with an apostrophe ('). These e-facial choreographic patterns are among the most expressive available.

Muscles: respectively lower lip depressor, brow raiser and the muscles of joy.

Muscle Matrix: $D_L \rightarrow {}'D_L$, $D_U \rightarrow {}'D_U$, $A_L \rightarrow {}'A_L$

Related: *brow zag, face flip*

Video: #27 (lip flip and brow flip)

Nose loop, mouth loop — a rotating movement pattern around the nose or mouth attractor. The nose loop affects the overall impression of the facial surface by pulling at its 'extremes,' the mouth loop just affects the muscles of joy and the lower lip depressor.

Muscles: lower lip depressor, the muscles of joy and brow raiser.

Muscle Matrix: ${}'D_L \rightarrow {}'A_L \rightarrow {}'D_U \rightarrow D_U \rightarrow A_L \rightarrow D_L$

Naming variant: *nose rot, mouth rot*

Related: *eye step* (rotation around eye attractor)

Video: #34 and "Huge Harry" @ 17:32 - 18:16 (nose loop), #32 (mouth loop)

Face X, mouth X — a flip operation (or rotation) around the vertical or horizontal axis affecting four muscles on the extremes with an alternating muscle-on state. A cross face or cross mouth diagonal is generated by pulling the face on either side into alternating counter extremes, i.e. brow raiser or muscles of joy on one side and lip depressor on the other. It is a good example of a symmetric muscle state with different operators that results in the same movement pattern.

Muscles: lower lip depressor + brow raiser or lower lip depressor + joy muscle.

Muscle Matrix: $D_L+{}'D_U \rightarrow {}'D_L+D_U$ or $D_L+{}'A_L \rightarrow {}'D_L+A_L$

Naming variant: *face cross, mouth cross*

Related: *nose loop, mouth loop* (depending on state pattern)

Video: #33 (mouth X) (face X: no video)

Face flop, face flip — a rare flip operation around the horizontal axis, an alternation between the symmetrical brow raiser and lip depressor. The operation affects the overall perception of the face. Similarly a complementary *face flip* operation is designated to a ‘full’ one sided flipping of the face to the other. This involves again the muscles that deform the surface to its extremes; the lower lip depressor, the muscle of joy and the brow raiser. A composite lip, brow and joy flip yields the same result. The face flop is an operation around the horizontal axis that requires a mapping definition (see Encoding chapter), here from the brow raiser towards the lip depressor.

Muscles: lower lip depressor, brow raiser and/or muscles of joy.

Muscle Matrix: $D_L+\text{’}D_L \rightarrow D_U+\text{’}D_U$ and $D_L+A_L+D_U \rightarrow \text{’}D_L+\text{’}A_L+\text{’}D_U$

Related: a *face flipflop*, as the reader might wonder is not defined, although technically it is a possible movement pattern. On the face of it, it does not seem to result in a clearly defined pattern due to overlap of the affected muscles.

Video: none

Face crush, face stretch, face throb — a contracting or expanding movement pattern affecting the perception of facial surface with a vertical directionality (see decoding section). It involves the brow depressor and lower lip raiser and respectively the lower lip depressor and brow raiser. A steady alternation of face crush and face stretch produces a pulsating or throbbing movement of the overall face; the *face throb*. The throbbing frequency is of importance, if the movement is to be perceived as throbbing.

Muscles: brow depressor and lower lip raiser and the lower lip depressor and brow raiser

Muscle Matrix: $B_L+\text{’}B_L + E_U+\text{’}E_U \rightarrow D_L+\text{’}D_L + D_U+\text{’}D_U$ (crush → stretch = throb)

Naming variant:

Video: none

Brow broom — an alternating movement of the brow, a simple up/down movement, that can either be single or double sided.

Muscles: brow raiser

Muscle Matrix: D_U | ’D_U → 0 or D_U+’D_U → 0

Naming variant: double sided; the *double brow broom*

Video: #27

Brow zag — a variation on the brow flip, a counter brow movement on either side of the median plane, pulling the brow up on one side and down on the other. A more pronounced zigzag movement effect on the brow can be achieved by adding an optional outer brow raiser to the side of the inner brow raiser.

Muscles: brow depressor, inner brow raiser (optional + outer brow raiser)

Muscle Matrix: E_U → ’D_U or optional F_U → ’D_U

Naming variant: *brow zigzag* for the more pronounced variant

Related: *brow flip*

Video: #37 @ 02:06 - 02:08

Eye step — a slowly executed sequential stepwise brow movement, a shift operation on the eye attractor. This brow movement is perhaps a little curiously named, but has remained for legacy reasons as it was first coded and observed in the piece “Arthur and The Solenoids.”

Muscles: inner brow raiser, inner/outer brow depressor

Muscle Matrix: A_U → D_U → E_U

Naming variant: *brow step, eye loop*

Video: “Arthur and The Solenoids” @ 01:34 - 01:39 or a 4 muscle eye step #37 @ 01:29 - 01:31

Brow swivel, brow flap — a rotate operation with an alternating muscle set on pattern, applied to the four muscles controlling the brow. A peculiar brow movement appears that I have never observed before. It is an odd movement that, being emotionally driven, will perhaps not easily appear, as it is the rapid alternating combination of two supposedly mutually exclusive emotions, i.e. contempt and reflection.[104] The outer brow is raised while the inner brow is lowered and vice versa in an alternating fashion. It appears that the brow rotates around a midlevel pivoting point.

When the rotate operation is mirror executed however the brow movement sequence becomes even more peculiar. The brow movement seems anchored at and moving along the median plane and consequently it almost resembles the flapping of the wings of a bird or stingray; the *brow flap*.

This newly-discovered movement pattern is an aimed for but still remarkable outcome from systematic choreologic probing of the dynamic face space. The future work section proposes to extend the probing efforts to uncover even more unseen movement patterns.

Muscles: inner/outer brow raiser/depressor

Muscle Matrix: $B_U \rightarrow F_U$ or double sided B_U+'$B_U \rightarrow F_U$+'F_U

Naming variant: *brow seesaw*, double sided; *double swivel* or the *brow flap*

Video: #30

Evaluating Artistic Experiments

All three artistic experiments, that is “Morphology,” “Face Shift” and in particular “Electric Eigen-Portraits” show vibrational states of the facial features. Similar resonance states were observed in a first facial choreography experiment from 1997 called “Arthur and The Solenoids.” The quivering or trembling state of the face or facial elements is an important e-choreographic feature, that has been thoroughly investigated in the section on muscle resonance. Although facial resonance patterns simply are the result of an increased muscle on/off frequency of the above e-choreographic patterns, it is worthwhile to designate it as a separate e-choreographic component, because it is perceived as a separate state. What follows are the facial elements with the most pronounced resonant states.

Lip twitch, brow thrash, cheek pound — a rapid lip flip results in a quivering or trembling state of the lower lip. The same accounts for the brow and the muscles of joy, but the

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[104] Perhaps this a postmodern state of mind?

resonance state of the individual one sided muscle can be just as effective. Prefixing the e-choreographic elements with a ‘rapid’ or ‘fast’ can be used as an alternative designation.

Muscles: lower lip depressor, brow raiser and muscles of joy

Muscle Matrix: $D_L \rightarrow {'}D_L, D_U \rightarrow {'}D_U, A_L \rightarrow {'}A_L$ or single sided $D_U \mid {'}D_U \rightarrow 0, A_L \mid {'}A_L \rightarrow 0$

Naming variant: *rapid lip flip, rapid brow flip/broom, rapid joy flip, joy jerk*

Video: “Arthur and The Solenoids” @ ~04:00 and “Electric Eigen-Portraits”

Face shake — a quivering or trembling state of the face as a whole. A compound of the lip twitch, brow thrash and cheek pound resonance states affecting the overall perception of the face.

Muscles: lower lip depressor, the muscles of joy and brow raiser.

Muscle Matrix: $D_L + D_U + A_L \rightarrow {'}D_L + {'}D_U + {'}A_L$

Naming variant: *face quake*

Video: “Arthur and The Solenoids” @ ~04:00 and “Electric Eigen-Portraits”

Brow wave — a move operation across the brows produces a wavelike pattern along the horizontal line of the brows. All three move operations shift, rotate and bounce can be used while the last one makes it appear somewhat akin a cylon left/right, above the eyes, brow movement.[105]

The brow wave is an example of a more complex sequential brow movement pattern where timing of muscle state is crucial for its effect. This movement pattern cannot be expressed in the limited muscle matrix notation because it lacks the notion of timing (muscle duration). It involves just four muscles; D_U and E_U and their complement ${'}D_U$ and ${'}E_U$. The brow wave was first observed in the “Huge Harry” performance.

Muscles: inner brow raiser and brow depressor (optional + outer brow raiser for a deep wave)

Muscle Matrix: cannot be expressed in matrix terms without becoming complex

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[105] A Cylon is a robotic entity that was introduced in the popular US TV series Battlestar Galactica that had a pronounced left/right movement of a red light in the place of the eyes.

Related: *eye step*

Video: “Huge Harry” @ 14:24 - 14:32

Jaw grind — left/right chewing-like sideways movement of the mandible. This pattern has been observed in various performances as a side effect of (excessive) multi-stimulus resulting in a level of parasitic stimulus of the masseter (and platysma) muscles. It is also a possibility that excessive pull on the facial features indirectly moves the mandible sideways. Jaw movements have not been formalized in the current instantiation of the language, but *the grind* is worthwhile to include.

Muscles: masseter, platysma

Naming variant: *the grind*

Video: #33

Summary

The e-facial choreographic nomenclature defined in this section describes the repertoire of the most important e-choreographic components or movement patterns, although a clear cut binomial naming scheme turned out not to be feasible. A good example of this naming difficulty is the so called *brow swivel* or *brow flap* for the two sided version of this unique brow movement. This previously unobserved facial movement pattern that choreologic probing has uncovered is not just peculiar in itself, it is just as hard to qualify.

Even so, the vocabulary presented is a good step forward in the formulation of and thinking about e-facial choreography. Future iterations of the e-facial choreography nomenclature will undoubtedly refine and improve upon the proposed specification and muscle matrix notation. To aid in this development process, it is proposed to create an online communal facial e-motion bank.[106]

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[106] More on this in the future work section.

5.3.The New Expressiveness of the E-Face

"Seeing that the nature of things betrays itself more readily under the vexations of art than in its natural freedom." Francis Bacon (1620)

"*One wears a face, one doesn't own it."* Adam Zachery Newton (1998, p.2)

The behavior of the e-face that we have seen in the experiments is consistent with the hypothesis made in the introduction. The e-face's behavior is more temporally accurate and consistent than a neurally operated face and is completely and easily programmable. Although the face can be voluntarily controlled by the brain, its expressiveness is severely limited by the agent's neural origin as we discussed in the Decoding chapter.

The analysis presented in this chapter has shown that as a result of systematic choreologic probing of dynamic face space, new movement patterns have emerged that have not been observed before. Digital computational control of the face has brought to the surface an embedded expressive potential that was previously unobtainable and therefore imperceptible.

Freedom of Facial Expression

Moreover, the brain's constant need to expose its internal state to the outside world, puts a claim on the face which is emphasized by the above quote by Adam Newton which is a rehash of Levinas' notion that the face resists possession. In "Nothing but face" — "To hell with philosophy"? Newton argues that the human countenance is an enslavement to the faces of others. It is rooted so deeply in our neurological functioning that he says: "The real scandal of countenance is that it is a conjoint phenomenon; no one — not even the readers — get a free look." and "One has to stare back and dole out grimaces and mugs in the same measure that they are received."

Arguably the hotly debated discovery of *mirror neurons* is the working principle behind these statements. Facial expressions are inexorable, the autonomous brain has the face on a tether whether we agree with this unsavory situation or not, the brain acts like a tyrant. The person wearing the face is in a constant struggle with the brain for control, a process explained before that Ekman named 'facial management.' A term that is far too detached from the real issue at hand, it is 'the scandal' as Newton strongly attests.

As artist and researcher, I assert the following philosophical position in relation to the practice of e-facial choreography described in this thesis: The “regime change” from neural to digital control over the face, puts an end to a despicable situation, the tyranny of brain over face. Consequently, the e-face brings about the embedded expressive potential of the face, unrestricted by the neural performative shortcomings. Philosophers Gilles Deleuze and Félix Guattari would roll over in joy[107] about this exquisite example of their *Body without Organs*[108] concept (Deleuze and Guattari 1980), meanwhile technology sceptic Paul Virilio would possibly knit his brow over this example of antihuman body art.[109] (Virilio 2000)

What is more important though is the emancipation of the face, a liberalization from subjugation of the tyrannical neural brain. External digital control has freed the face, an unencumbered facial expressiveness has emerged, that allows the face to express more of its inherent logic and physical self. Pointedly expressed, the externally controlled human face can be said to have attained *freedom of facial expression*, which could be considered as being a realization of the hacker ideal. However, such a view is potentially contentious.

Democratization of Facial Access

“Once we have surrendered our senses and nervous systems to the private manipulation of those who would try to benefit from taking a lease on our eyes and ears and nerves, we don’t really have any rights left.” Marshall McLuhan (1964, p.68)

Not only is the face emancipated, it is also made communist in the sense that it can be equally accessed by anyone or any (remote) process. “rEmote” the piece from 1995 where the face was directly wired to the internet, exemplified universal global access to the face. It allowed anyone in the world to use the facial display of another for any purpose they could see fit. One of the uses that comes to mind is for example facial ventriloquism. The e-face has given rise to a direct *democratization of facial access* on the controlling hardware level.

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[107] Unfortunately both passed away in the 1990’s.

[108] The concept that bodies have a ‘virtual’ dimension, an untapped expressive potential that can be brought about in a ‘becoming.’ It is my opinion that the best body is the one without a neural brain.

[109] See also Virilio’s brief condemnation of Dr.Duchenne’s ‘medical art.’ (in quoted form in the original text) (Virilio 2000, p.40)

Zweckentfremdung

Through the change of agency (see Decoding chapter) and evidenced by the choreologic probing of dynamic face space, the human face has been *recoded* on multiple levels. The human face has become a site for computational expression and as such has become an abstract or generic display device. This has set in motion a new expressiveness for the face that acquired its own system of rules in the Language of Facial E-motion with its inherent choreologic, muscle matrix notation and e-choreographic nomenclature.

The human facial display has been recoded to express 'meaningless' movements of the facial features that transcend the expression of the emotions. Although the viewer can interpret an individual (static) expression as related to an emotion, the rapid succession of often emotionally conflicting expressions negates the interpretation of the movements on a distinct emotional level. My pet theory about e-facial expression and the effect on the psyche of the viewer is a disparity in the concurrent and rapid firing of the mirror neurons. It is as if the brain is chasing a chimera, an emotional state it can never achieve. This hypothesis is supported by the earlier mentioned girl at a performance at the San Francisco Art Institute that actively tried to follow with her own face the observed expressions and reportedly got mentally confused. Artistically this effect is all the more interesting as it seems to keep the brain of the viewer occupied.

A consequence of external facial control is the furthering of the aforementioned emancipation and democratization of the face; a recoding on the meta level. Considering these issues it appears the human face has entered a stage in which it no longer adheres (as if it ever was) to the person wearing the face. It has moved from its 'intended' purpose of displaying the emotions to the display of abstract movements, choreographed by a fully programmable and possibly remote machine. The recoding of the face is a prime example of hacking that Thomas Düllo cited in the introductory chapter typified as *Zweckentfremdung*, a repurposing with the possible outcome of alienating the original intend.

Summary

This chapter described the recoding of the facial display on multiple levels. The facial display has been literally recoded by designating names to unique e-facial choreographic movement patterns. The binomial naming scheme that is used is based on a facial feature or element and a choreologic operation or if not feasible on the observed movement pattern. This has resulted in an e-facial choreographic nomenclature or vocabulary that in cases had to resort to the twisted logic of artistic designations; for example, when a compound designation has some linguistic resonance, e.g. the brow broom or face shake. Although the *lip flip* for example could adhere to the strict choreologic operation. Systematic choreologic probing also uncovered a new abstract movement of the brow that currently is named the *brow swivel* and when doubly executed as *brow flapping*. The chapter further introduced the muscle matrix notation system that permits the description of facial movement patterns. The system is limited to only describe muscle set state change, and cannot describe duration or timing.

The facial display has also been recoded on a twofold meta level. Wiring up the face to an external control system has detached the face from the tyrannical control by the brain. As a result from digital control over the facial features, new facial behavior has emerged. An embedded and previously unknown expressive potential has been unleashed which allows the face to express more of its physical self instead of being held back by the performance limited neural brain. Digital in comparison to neural computation is far superior in (temporal) accuracy, speed, consistency of execution and programmability. Emancipating the facial display from subjugation of the brain has attained *freedom of facial expression.*

The second meta level of recoding is that external facial control allows external processes to access the facial display for use as a site for computational expression. Any external process can have unrestricted access to a possibly remote facial display, it is made communist and by this method has consequently attained a *democratization of facial access*.

Finally, on the meta meta level, hacking about with external control over the facial hardware has led to an alienation of original purpose that Thomas Düllo has typified as *Zweckentfremdung*.

In conclusion we can say that the human facial display has been recoded on multiple levels, and as such the human face has entered a new (evolutionary) phase.

Chapter 6

6.Conclusion

“It's about the differences between neural and digital computation and this makes all the difference.” John von Neumann (1958) [110]

6.1.Contributions

The contributions of research described in this thesis include the following.

A Radical New Way of Thinking about the Human Facial Display
The rewiring of the human face to an external digital control system, has sparked a radical new way of thinking about the human facial display. Radical, as facial movement is now rooted in digital instead of neural computation. The human face has become an extension of a digital control system inheriting its characteristics: i.e. temporal accuracy, consistency of execution and high programmability. External digital control over the facial muscles solves an addressing problem identified in the background chapter, where existing facial exploration methods were found to be too limited in their access and control capabilities.

As such the human facial display has become a site for digital computational expression. Consequently digital computation allows for an exploration of the facial dynamics in a hereto unprecedented systematic manner which has uncovered new movement patterns. The results coming out of this facial exploration effort is a substantiation of the research’s claim that the human brain is underutilizing the inherent expressive potential of the facial hardware. Post-neural exploration transgresses the neurally induced performance limitations and enables us to think about facial movement from a digital computational choreographic paradigm.

To aid in exploring this new found expressive potential, the research has developed conceptual and practical tools in the form of a language definition and facial control hardware.

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[110] A summary of John von Neumann’s “The Computer and the Brain” in the form of a quotation.

The Language of Facial E-motion

The explorative facial language or framework that is defined, the *Language of Facial E-motion*, lays down the basic elements for computational e-facial choreographic pattern generation. It defined theoretic logical operations on muscle sets, identified facial attractors, and consequently proposed a *choreologic of the e-face*, which mapped the logical operations onto the topological attractors. Fundamental e-facial choreographic parameters like muscle speed, resolution and resonance were defined by means of practical measurements.

The choreologic operations as defined enables systematic probing into a consequentially reduced dynamic face space, generating a large variety of e-choreographic facial movement patterns.

The Electro-Facial Choreographic Nomenclature

The *Electro-Facial Choreographic Nomenclature* describes the unique and fundamental e-facial choreographic movement patterns that came forth from choreologic probing of dynamic face space. The vocabulary describes e-facial movement patterns in a simple binomial scheme identifying a facial element and an operation or an observed movement pattern. This systematic choreologic probing unveiled for example some new facial movement patterns that in the vocabulary have been named the *brow swivel* and *brow flap*.

The vocabulary that describes the fundamental e-facial choreographic patterns, that is introduced in this thesis, is a way forward in the conceptualization of new e-facial choreography pieces, while it also allows to structurally analyze previous work.

Innovative Facial Control System, Multiplexed Multi-Muscle

The digital electric facial muscle stimulus system that was developed in the course of this research makes a contribution to the art of external muscle control by using mono-phasic, multiplexed stimulus currents. It allows simultaneous control over a large number of facial muscles without the need for relatively large localized bipolar electrodes cluttering the facial surface. This innovative solution therefore offers a more aesthetically appealing end result, which is of great value for e-facial choreography.

The New Expressiveness of the Human Facial Display

As artist and researcher, the philosophical position is asserted that the external control of the human facial display has triggered an emancipation of the face, since the face has been freed from subjugation by the neural brain. The human facial display can be freely programmed without neuronal restrictions. Facial expressiveness has been extended beyond the bounds of the neural performance capabilities, uncovering a new expressive potential that pointedly and metaphorically can be expressed as having attained *Freedom of Facial Expression*.

The human face by means of external control has become a generic computational display device that on the hardware level can be accessed by any external, even remote process. This in effect has resulted in a *Democratization of Facial Access*.

External control has alienated the human face from its original purpose of displaying the emotions or the emphasizing of the spoken word. A *recoding* has taken place, a repurposing of original intent, that by Thomas Düllo, in hacking terminology, has been typified as *"Zweckentfremdung."*

Facial Hacking: Neither Art, Science or Technology

The interdisciplinary work presented in this thesis has generated output that does not fit particularly well into any one of the three disciplines or fields of human endeavor, art, science or technology. The final e-facial choreographic vocabulary came forth from a progressive, entangled process of technical innovation, scientific analysis and artistic interpretation with the aim to ease the development of artistic output. It seems more akin of a "ménage à trois" that created its own play field on a space in-between, a sweet spot, taking elements from each of the disciplines to forge its output.

It resembles the results oriented method of hammering something into place or hacking. Thomas Düllo in "Cultural Hacking" writes: "Hacking produces experimental research methods for a precise and calculated intervention in the system, also when from viewpoint of the system these seem irregular or unprofessional. In reality such an intervention is more likely artistic. That is to say the hacker links the (analytic-systematic) practice of the engineer and scientist with the (creative-playful) practice of the artist." (Düllo and Liebl 2005, p.29)

Facial hacking, as presented in this thesis, can be of value to the discussion about cross- or interdisciplinary artistic research. It shows how each of the involved disciplines added value to the end result and as an example of research that is clearly positioned in-between disciplines.

6.2. Future Work

In this penultimate section, I explore and discuss some potential future directions for the language of facial e-motion, the facial control system, and new applications. Some of these are already underway at the time of this writing. All of these await new research and is believed to hold good potential for continuing to provide new ways of thinking about the facial display as a site for computational expression.

6.2.1. Language Development: Extending and Formalizing

At the time of this writing, we have established the groundwork for specifying e-choreographic facial movement. We have found a good set or repertoire of basic e-choreographic movement patterns that will find good value in the creation of new e-facial choreographies, but there surely is room and desire to further extend and formalize the language.

Language Extension

The language so far included the most expressive muscles of the face, which we call the electro-expressive muscles. For various reasons we excluded subtle and even some highly dramatic facial movements like the opening of the mouth by lowering of the jaw.

This last one is clearly an omission in e-facial choreography that should be incorporated in a future language definition. Movements of the head itself were also not included in the e-choreographic repertoire. However, a very early experiment I made in 1993, dubbed "Head Turner,"[111] has shown the wiring up of the paired sternocleidomastoid muscles can produce some excellent dramatic effects. By nature of the muscle mechanics, an individually contracted muscle makes the head turn left or right, while simultaneous contraction lets the head fall forward. A prime candidate to add to the e-choreographic, beyond the face, repertoire.

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[111] The performance setup consisted of two microphones at either side whose audio signals were amplified and converted into electrical stimulus currents. The audience could ask (scream) for attention at the microphone, but the head would always turn the other way, erupting in a 'battle' for attention with the other side. Performance took place in Paradiso Amsterdam, but title has been lost.

Figure 6.1: "Head Turner" performance Elsenaar, 1993, stimulating the paired sternocleidomastoid muscles. Head moves right or left when individually stimulated or down when both muscles are stimulated simultaneously.

More subtle facial movements can be added by incorporating into the system more of the 7th cranial innervated muscles; for example orbicularis oris and risorius both affecting the mouth, levator labii superioris, the nose wrinkler, and a subtle movement of procerus that pulls the eyebrows together. Perhaps a *blink flip* can be added to the language as Jonathan Post has recently shown. A video of faked research results shows the alternating eye lid movements in accordance with the displayed image on screen producing a supposed perception of 3D. [112]

Choreologic probing of dynamic face space has uncovered a good set of basic e-choreographic movement patterns. Extended probing and analysis, especially around the mouth attractor, will likely identify more e-facial choreographic movement patterns. The nomenclature so far defined is not meant to be a static designation of movement patterns, but will be refined and extended in future developments. The presented research in this thesis takes a few steps towards the creation of a comprehensive but perhaps never complete e-facial choreography.

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[112] The video "3D No Glasses" at http://www.youtube.com/watch?v=Uef17zOCDb8 and http://www.jonathanpost.com/ for an explanation.

Higher level choreographic functions can extend the language to describe more complex movements of the face. Imagined here are the definition of functions to compact a series of e-choreographic movements in a single statement. For example the aforementioned single *morph* statement, where a (slow) interpolation from one muscle set state to another is executed, but far more complex movement patterns can be assembled in one statement.

Language Formalization

The definition of the Language of Facial E-motion was designed with pragmatism in mind and for that reason, did not strive for linguistic correctness or formalization. This might be accomplished, but more research is needed in the structure of languages in the context of the complexity of the human face. On the horizon lies perhaps a new choreologic of the e-face that is fully consistent in linguistic terms.

However, the e-facial choreographic nomenclature that has been developed might remain difficult to formalize as a strict logic because of a dissimilarity between the choreologic operations and the observed facial movement patterns.

The research further determined, by means of experimental measurements, the essential e-facial choreographic parameters of muscle speed and resolution. These measurements can be improved upon in their execution and quality of outcome, which will make it possible to express these two muscle parameters as respectively a physical facial element displacement per time unit and a straightforward JND (Just Noticeable Difference).

Not strictly part of the Language of Facial E-motion, we designed the “totem pole” Muscle Matrix Notation system as an aid for describing and visualizing facial movement patterns. The matrix is not complete, and for this reason was designed with expansion in mind. More attractor muscle set permutations can be added, however incorporation into the system of the essential e-choreographic parameter of duration and timing would require the introduction of a timeline or similar time based construct.

Facial E-motion Bank

The Language of Facial E-motion, the E-facial Choreographic Nomenclature and Muscle Matrix totem pole notation will be made available in an online database, the *Facial E-motion*

Bank, with the aim to bootstrap a community of e-facial hackers and choreographers. The vocabulary so far defined can be extended and re(de)fined and it is thought and hoped an evolving community can help to establish e-facial choreography as an emerging genre. In support of this aim, the next section proposes to open-source the new controlling hardware as well.

6.2.2.Facial Control System: Interfacing Enhancements

The facial muscle control system that was developed for the research, is a refinement on the previous generations of devices that I developed. The first developed digital muscle stimulus system introduced the innovative multiplexed electric stimulus scheme, which remained and was improved upon in safety and comfort of the stimulus impulses.

The system became complex due to a number of added features; battery operation and management, on screen visualization of stimulus levels and calibration interfacing elements. Under way at the time of writing is a simplified system that separates the electric stimulus electronics from the interfacing hardware, doing away with many of the above introduced system complexities. Recent developments in smart phone technology like iOS/Android makes it feasible to have superior interfacing and battery management technology at an affordable price. Added to these convenient developments is that the facial control device can make use of advanced wireless communications capabilities of these devices, which is of importance for synchronous multi face choreographies in portable setups.

Additionally, these devices all have an accelerometer[113] on board that enables new interfacing opportunities; imagine for example that a shaking up/down motion of an iPhone might trigger the *face flop or face shake* in complete unison with that movement. A — do the face shake — might become a new facial dance genre.

The touch screen of these devices can offer a much better user experience in muscle calibration procedures than the thumb wheel on the original device and is great for visualizing actual electric muscle current. The high resolution screen will also be explored as an e-choreographic compositional and visualization tool, where movement sequences can be 'patched' together in simple choreographies. It will be of great benefit to compose choreographies 'off line' and study facial movement sequences in an on screen simulation.

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[113] An advanced sensor that measures acceleration in three directions.

My expectation is that in the future a lap- or desktop machine for running facial choreographies will become redundant, all can be done on a portable phone or tablet platform.

Complementary to the online facial e-motion bank, the new system will be open-sourced and also made available online, which will hopefully encourage more people to become involved in this exciting new area of performance art.

6.2.3. Facial Orchestras and Other Artistic Opportunities

The impact of e-facial choreography, the unnaturalness of the facial movements on how it is perceived can be much improved upon when two or more faces are controlled in unison. Facial orchestras where multiple faces are synced to pop music for example can be great for a video clip. In fact work is under way with US band “Ok Go” to do just that, imagine a *brow wave* for example that extends from one face to another.

An interesting outcome from the research is facial muscle resonance. We have designated the *face shake, lip twitch* and *brow thrash* as e-choreographic components, it shows great potential for new pieces by mapping these onto music with similar characteristics. What about a popular “Drum ‘n Face” [114] or an avant-gardist “Chorea Chorus.” [115]

The background chapter highlighted the *Tronie,* a Dutch seventeenth century informal painting style. A type of figurative painting depicting heads that had an odd character or other exceptional expressiveness. As the e-face can generate remarkable facial deformations, a new type of portraiture is envisioned that shows the face in a perpetual changing state. Recorded on high definition video and displayed on high resolution flat screens, a kind of *moving portraits* can be created that are close to the original tronie; “ElekTronies,” a merger of the Dutch words for elektronisch (electronic) and the plural form of tronie (head). [116]

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[114] Title suggestion by artist Perry Hoberman.

[115] Oxford Dictionary: chorea, a neurological disorder characterized by jerky involuntary movements affecting especially the shoulders, hips, and face.

[116] Title suggestion by artist Taconis Stolk.

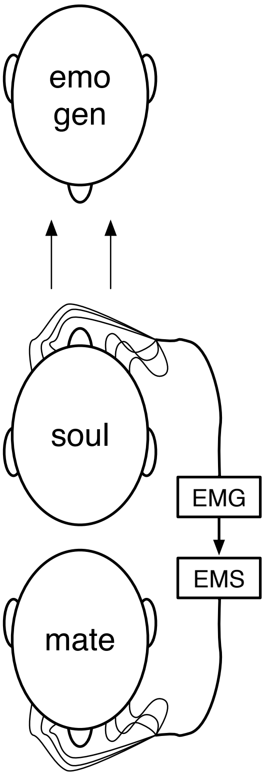

Figure 6.2: “1+1=1, the scandal” Performance/research to ‘proof’ the existence of mirror neurons.

A few times in the thesis we discussed the mirror neuron as a suggested mechanism behind the autonomic human countenance. It is an observed fact that an automatic neural reflex triggers the muscles in the face when an emotion comes about or, if mirror neurons exist, when another face is observed. Even when neural activity induced by emotion or mimicry does not lead to a pronounced (visible) facial muscle contraction,[117] neural activity can be measured by an electromyogram (EMG).

The artistic research/ performance that is envisioned, is a two stage facial mapping in a threefold stage setup. The aim is to measure this invisible neural activity on one subject and map it onto another subject by stimulating the exact same muscles as the ones detected. In this way, an emotion amplifier is constructed, that offers a view into someone’s brain or emotions rendered on the face of another. The emotions on the first subject are triggered by viewing a third subject that voluntarily pulls faces at the first. This third person could be a member of the audience. The working title for this experiment is “1+1=1,” a visualization of what Newton called “the scandal.” (Newton 1998)

These new artistic research areas are on the post-PhD agenda and some are actively being worked on.

6.3.Concluding Remarks

In this thesis, we presented the computer controlled human face as a new medium, together with ideas, design goals, language specifications, context, and the various ways of thinking associated with it. Additionally, we examined the deployment of the language in a series of systematic experiments to probe dynamic face space, and evaluated the outcomes as the basic elements or vocabulary of an e-facial choreography. While much has been investigated, perhaps even more remains to be discovered and explored. I hope that with this thesis and the

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[117] The subject can be involved in so called facial management, i.e. an Ekman micro-expression.

open-sourcing of its tools, the investigation continues, remembering that while technology allows us to control our lives, technology is just about to control life itself.

Now release those brows voluntarily.

Post-face

“Electricity will take the place of God. Let the peasant pray to electricity: he’s going to feel the power of the central authorities more than that of heaven.” Vladimir Ilyich Lenin (1918)[118]

“All stable processes we shall predict. All unstable processes we shall control.”
John von Neumann (ca.1950) [119]

After reading this thesis, the reader might wonder what lies ahead of the computer-controlled human face. Can post-neural digital exploration be extended to other biological entities?

In the Pre-face I presented my view of the digital computer as a box full of switches that allows electricity to be controlled in fine detail. This ultimate malleability of electricity makes possible an unprecedented capacity to control, that likely surpasses Vladimir Lenin’s wildest dreams about the impact of electricity on society.

At the dawn of the digital revolution, John von Neumann, the computer science pioneer, also recognized the enormous power to control as evidenced in the above quote from around 1950. Subsequently, the digital revolution has conquered, penetrated and changed almost all aspects of life except perhaps life itself.

However, what my research has shown, is that the ongoing digitalization of the world does not stop in the inorganic, but has crossed into the biological domain and is changing it on a fundamental level. The results coming forth of the present research shows that the superior qualities of digital computation allows the biological to perform in unprecedented ways, releasing a latent functional potential.

It raises the question if other biological entities could take advantage of digital computation as well. The answer is an unrestricted “yes.” A new artistic playground may lay ahead that merges the biological and the digital in a new field of “BioLogic media.” Not to be confused with the old cyborg dream of enhancing human capabilities by embedded

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[118] (Glinsky 2000, p.9)

[119] Freeman Dyson wrote his recollection of a talk given by Neumann at Princeton around 1950. The words are not a direct quotation, merely Dyson's description of Neumann's idea. (Dyson 2004, p.182)

technology. BioLogic media are not restricted to the human, it extends to any biological entity, whether this is cultured (animal) tissue or complete organisms.

In the future we might see BioLogic artworks that are amalgams of digital control logic and biological sensors and actuators. The culturing of (animal) body parts that this requires, might take on an entirely new meaning, as perhaps the notion of life itself.

BioLogic media is a largely unexplored area that is open for exploration in the decades to come, but whether artists will be able to dance at the BioLogic party, will remain a question of who is in control of the — ethical — shorted power plug.

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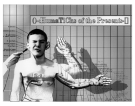
Appendix A

A. Schematic Timeline of Artistic Development

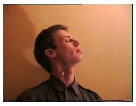
1993


BODY CONVENTION
radar controlled human sculpture
analog electronics



HUMATICKS OF THE PRESENT
voice controlled bodily movement
first digital and wearable electronics:
multiplexed muscle stimulus 8 channel

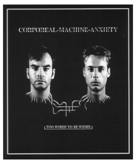
1994


HEAD TURNER
(STERNOCLEIDOMASTOID)
voice controlled head movement
analog electronics


ARTIFICIAL HANDICAP
unobtrusively wired
autonomous erratic
lower lip movement

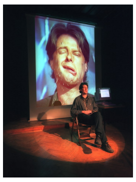

DIGITAL MUSCLE
CONTROL DRAWINGS
lecture with demonstration
algorithmically controlled arm and hand
collaborator: Remko Scha

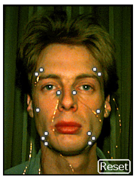
1995



CORPOREAL-MACHINE-ANXIETY
first performance lecture
public interaction through voice input,
collaborator: Eric Kluitenberg


ONTVANGER
(RECEIVER)
facial expressions controlled by radio

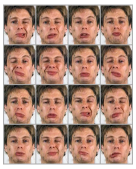

HUGE HARRY:
TOWARDS A DIGITAL COMPUTER
WITH A HUMAN FACE
performance lecture
electronics expanded to 16 channels
collaborator: Remko Scha



REMOTE
a.k.a. COMPOSE YOUR EMOTICON
remote external control through internet


ROBOT RIGHTS RALLY
political demonstration for / by machines
collaborator: Remko Scha

1996

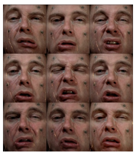

THE VARIETIES OF
HUMAN FACIAL EXPRESSION
(12 BIT VERSION)
systematic exploration of static face space
programming: Remko Scha

1997

ARTHUR AND THE SOLENOIDS
automated guitar band with
accompanying e-facial choreography
MIDI interface
collaborator: Remko Scha


MORPHOLOGY / FACE SHIFT
algorithmic e-facial choreography
programming: Remko Scha

2005


ELECTRIC EIGEN-PORTRAITS
systematic exploration of
facial muscle resonance phenomena
programming: Remko Scha

2007

RAW LAB EXPERIMENTS:
DEPLOYING THE LANGUAGE OF
FACIAL E-MOTION
choreologic probing of dynamic face space

2009

Appendix B

B. Myology

In this appendix chapter, a basic understanding of myology or the study of the *arrangement*, *structure*, and *action* of muscles is presented. It discusses how the facial muscles are arranged around openings in the face, and how these different openings share a similar structure. It will then zoom in on the workings of the muscle itself as an electro-mechanical actuator. The chapter concludes with a discussion on practical issues involved in electrical stimulation of the facial muscles.

B.1. Muscle Arrangement

The human facial musculature shares its construction with other primates and is believed to be derived from two very simple systems, the platysma myoides and the musculus sphincter colli which form a kind of grid around the skull. (Preuschoft 2000, p.255) These muscle systems extend from the neck and back and are differentiated into smaller muscle subsystems that enable the movement of the ears, eyebrows, nostrils and mouth, arranged around orifices, as the most important moveable elements of the face.

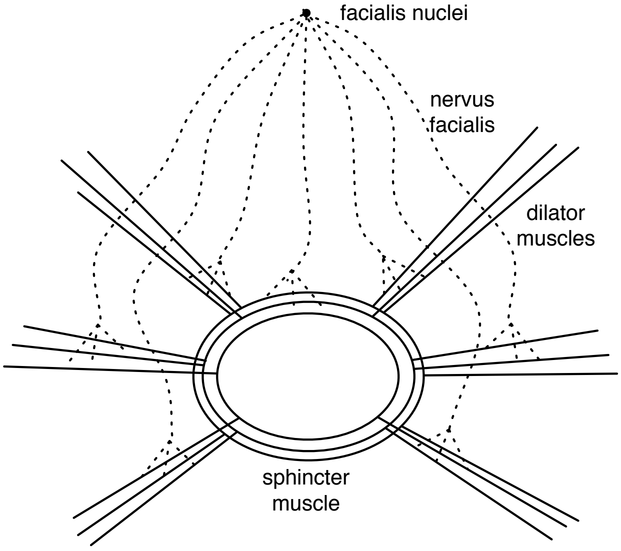


Figure A.1: Schematic representation of an orifice consisting of a sphincter and dilator muscle arrangement.

The orifices of the head all have a similar construction with a ring or sphincter muscle surrounding the opening and dilator muscles attached directly or indirectly to the sphincter muscle which by their contracting action pull at the orifice. Dilator muscle on one end are attached by way of an elastic tendon to the bone structure of the head and on the other end to the sphincter or other soft tissue surrounding it. An abstract representation of the sphincter with surrounding muscles, taken from Hjortsjö is given in figure A.1. (Hjortsjö 1969, p. 44-45)

The pulling actions of the sphincter muscle and the dilator muscles produces a complex resultant of forces deforming the orifice and surrounding tissue into a multitude of shapes. The sphincter can narrow the opening and the dilators, pulling at the opening, deform the surrounding tissue into bulges and furrows which are called facial expressions. Due to the complex anatomical layering of the different pulling muscles, the deformations around the mouth that result from the pulling forces are very difficult to predict, and lead to an almost infinite variety of facial patterns.

The mouth adheres rather closely to the abstract model given here. The orifice of the eyes with eyebrows and eyelids has evolved differently, but the basic structure is clearly similar[120]. The mimic muscles of the face are innervated by the nervus facialis or seventh cranial nerve originating in the brainstem in an area barely larger than a pinhead[121] (Hjortsjö 1969, p.46). Voluntary and involuntary nerve signals from the cortex and emotional centers of the brain are routed to this single point that controls the facial display.

Different researchers have studied the complex of pulling muscles and skin deformation in order to make sense of facial expression. In the Decoding chapter of the present thesis, we look more closely at this research.

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[120] In the research the opening and closing of the eyelids and the operation of the nostrils is ignored as it has proven to be difficult to control externally.

[121] Note: the fifth cranial nerve, servicing the masseter, the chewing muscle, is also important for facial expressiveness.

B.2.Muscle Structure

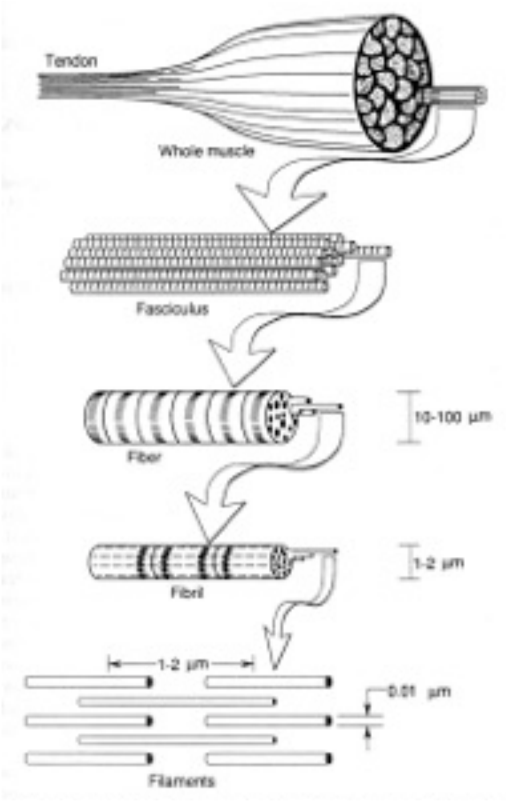

Figure A.2: Muscle structure (Taken from Reilly, 1998)

Muscles are actuators that in operation pull both physical ends together by exerting a considerable force at the points of attachment. Muscle contraction not only shortens the muscle, but also increases its thickness, which contributes to the deformation of the facial surface.

The anatomical illustration in figure A.2 taken from Patrick Reilly (1998, p.99) shows progressively smaller systems of structural elements of the muscle. A functional description of these elements will explain the muscle contraction phenomenon to the most fundamental protein level.

Skeletal muscle is a type of contractile tissue that consists of bundles of muscle fibers. It is called *striated* because of the microscopically visible striations that arise from the arrangement of contractile elements. It is one of two types of muscle found in the human body, the other *smooth* type is not under voluntary control as the skeletal muscles and can be found for instance in the intestines to move substances around.

Muscle fibers come in two flavors; red and white, also indicated by *Type I* and *Type II*. Depending on muscle function, most muscles have both types in a ratio determined by their ability of fast response and tenacity. White muscle fibers which are mostly found in long muscles have a high density of contractile elements and therefore can respond quickly but have less tenacity. Red muscle fibers, on the contrary, found mostly in wide short muscles have fewer contractile elements; they exhibit slower response times, but higher tenacity. (Gillert, Rulffs and Boegelein 1995, p.55)

Evidence exists that the fiber type of a motor unit[122] is not fixed, but under influence of its use can transform the fiber type population (Reilly 1998, p.306). Repeated muscle

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[122] Muscles used for locomotion.

stimulus as a result from stage performance might therefore transform response time and strength of the (facial) muscles, just like an athlete improves its performance by repeated training.[123]

On the next level, muscle fibers are composed of even smaller elements called myofibrils that stretch the whole length of the muscle fiber. A fiber contains between hundreds to several thousands of myofibrils that have a size of approximately 1-2 µm. Each myofibril along its longitudinal axis has a repeated pattern of filaments called sarcomeres. Sarcomeres are the actual contractile elements that by its shortening creates tension along its longitudinal axis. Many sarcomeres in series produces a shortening of a single muscle fiber. The resultant of the tiny forces of many shortening muscle fibers in parallel produces force or muscle tension.

Huxley (not sooner than 1954) put forward the theory of sliding muscle filaments by observation of frog leg tissue. He noticed a sliding interaction of two contractive proteins, actin and myosin, that form the basis for the muscular contractile phenomenon. (Parke and Waters 1996, p.228)

B.3.Muscle Action

Facial muscles are orchestrated by the brain acting as a controlling agency. The brain can exert remote control over the muscles by the body’s wiring; the nerves. Nerves are a type of electrically excitable tissues, they don’t have a physical response like the muscles, but are able to send along an electrical impulse.

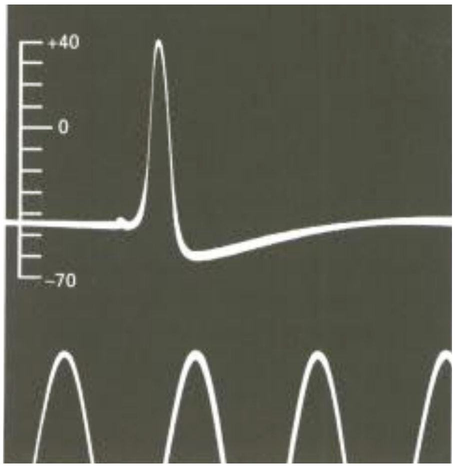

Figure A.3: First recorded action potential of the giant axon of the squid, Hodgkin and Huxley, 1939

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[123] Issues of athletic face-ism.

Hodgkin and Huxley in 1939 recorded for the first time the electrical behavior of the giant axon of the squid[124] (Figure A.3). Across the axon's cell membrane the electrical potential was recorded when the nerve became active and hence the electrical event was named *action potential* (AP). The graph plots the changing membrane potential, in the millivolt range, when an event occurs. Hodgkin and Huxley were also able to mathematically model the action potential for which they received the Nobel Prize in Physiology or Medicine in 1963.

In the human body action potentials of nerves are fundamental for signaling purposes. A chemical process of electrical re- and depolarization across cell membranes causes a wave front to travel along nerve dendrites to connecting nerve cells, thereby passing along the electric signal. Myelinated nerve cells as found in the motor nerves, have an outer sheet that speeds up propagation of the action potentials reaching speeds of about 100 m/s. Of note is that temperature plays a role in propagation speed, where higher temperature increases speed. (Gillert, Rulffs and Boegelein 1995, p.44)

When an action potential transmits along an efferent (from the CNS) motor neuron it terminates in the muscle in an area called the end-plate or *motor point*. The motor neuron branching out in the motor point are together known as a *motor unit*. The action potential event arriving at the end-plate, causes the release of a chemical neurotransmitter across the nerve/muscle gap which causes depolarization of the muscle cells. The muscle membrane is excited and a depolarization wave is propagated in the muscle tissue away from the end-plate region.

This process results in a single contractile quantum called a *twitch*. A rapid succession of action potentials is needed to achieve muscle tension, i.e. a fusion of individual twitch quanta as illustrated in figure A.4. About 80 twitch quanta per second are needed for maximum muscle tension, a condition which is called muscle *tetanus*. (Reilly 1998, p.98) Tetanus level can be finely controlled by the twitch quantum rate.

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[124] Recordings of neuron electrical activity by means of a cathode-ray oscillograph was first done by Erlanger and Gasser in 1923. They proved the hypothesis that thick nerve fibers conducts impulses faster than thin ones. (Erlanger and Gasser 1937)

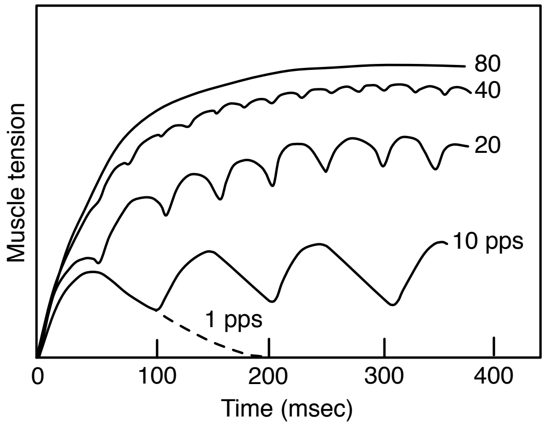

Figure A.4: Individual twitch quanta fusing into muscle tetanus. (Adapted from Reilly 1998)

Otto Gillert notes that by (artificially) increasing the AP rate or frequency to above 80 Hz muscle fatigue sets in, resulting in a fibrillation-like contraction leading to a relaxation(!) of the muscle. Gillert also reports the twitch duration time for fast white, and slower red muscle fibers, about 30 ms and 100 ms respectively. (Gillert, Rulffs and Boegelein 1995, p.56,58) Muscle response (and relaxation) times are important factors or parameters for e-facial choreography and therefore are more closely examined and determined by practical measurements in the Encoding chapter.

Precisely controlled movement in the locomotor system of the human body, relies on feedback information about the muscles state. The muscle action control system therefore is completed by muscle embedded sensors known as *muscle spindles* that through afferent nerves signal muscle length (contraction level) and the rate of change (of muscle length) back to the central nervous system. A second type of sensory receptors, the Golgi tendon organs lie in series with muscle fibers where they enter the tendon and these measure muscle tension. This information is used by an autonomous control loop, the well-known stretch reflex, to adjust muscle tonus (the constant low-level activity) to a task's requirements.[125] Accurate and controlled movement needs this feedback information, but in the face no muscle spindles have been found. Controlled movement is made possible by feedback obtained from embedded receptors in the skin that measure stretch and movement. Since in the face position and movement of the skin are important for the display, it is the skin that provides this feedback. (Cole 1999, p.49)

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[125] A noteworthy property of the autonomous control loop, is that it cannot quickly change to a new requirement. This results in a slowness where muscles are temporarily stuck at a certain contraction level.

Appendix C

C.Electric Muscle Stimulation

Muscle action as we have seen, is brought about by electrical events presented at its motor point. External electrical impulses can be administered to the muscle, triggering it into contraction, bringing about a similar response to that of stimulation by the nervous system. External excitability of muscles, lies at the core of the research and therefore warrants a deeper understanding of the problems of controlling muscles by electrical stimulation. This appendix chapter discusses different types of electric impulses that can be used to trigger muscles, and their benefits and shortcomings, also different ways of accessing the nerves, types of stimulus methods, issues on electrode placement and size, safety and comfort issues, and finally the physiological and psychological problems caused by electric currents flow through the wet living human body.

C.1.How does electric stimulation of muscles work?

From the previous discussion it became clear the muscle can be excited by the application of action potentials at its motor point. Artificially eliciting action potentials in the motor nerve is an effective way to achieve muscle contraction. This can be achieved by external application of electrical field inducing electrical currents, that give rise to action potentials. These then, as normal, propagate through the nerve and muscle thereby invoking twitch quanta.

It turns out that direct electric stimulation of the muscle fibers itself works as well, but requires much higher currents than the stimulation of motor nerves. External stimulation of the nerves therefore is much more efficient (Reilly 1998, p.98) and is the method the research has adopted for the external control of the facial muscles. As electrical motor nerve stimulation indirectly causes muscular contraction, in this thesis, the terms muscle and nerve stimulation are used interchangeably.

C.2.Types of electric muscle stimulation

C.2.1.Direct, pulsed and alternating currents

The background chapter briefly dipped into the history of electricity and how electric muscle stimulation in the arts has evolved. After Volta's invention of the voltaic pile, electrical experiments on biological tissues, were mostly conducted by the application of continuous or direct currents provided by Volta's battery, but were named 'galvanism' after indebtedness to Galvani's historic discovery.[126] Although in electrical engineering the term 'direct current' (DC) is now used, 'galvanism' is still in use today to describe the therapeutic use of direct electric currents on the human body.

Direct currents can invoke a single action potential or muscle twitch which can be brought about by an electric or physical contact event at the electrodes. A sustained contraction of a muscle (tetanus) requires the fusing of individual twitch quanta, which can be achieved by rapid on/off current transitions (pulsing), just as in a natural succession of action potentials.[127] It was the French professor S.Leduc in 1903 that first described the pulsed galvanic current (*Leduc current*) for stimulating muscles. An advanced apparatus consisting of an electric motor driven interrupter,[128] that allowed, for the first time, full control over strength, duration and frequency of the stimulating impulses. (May 1911)

Another type of stimulating current is 'faradisation,' named after Michael Faraday (1791-1867). In 1831 Faraday mounted a secondary coil around the primary coil of the relatively new interrupter which induced a current in the secondary. This secondary current is characterized by continuously changing direction and is therefore called alternating current (AC) or when bodily applied as 'faradisation.' Induction can be used to transform a primary current of low voltage into a higher voltage of lower current. The Faraday coil made it possible to use simple batteries to achieve higher stimulating voltages. Faradisation of the facial muscles was extensively used by Duchenne to achieve his outstanding results.

The stimulation of nerves and muscles is mostly done with pulsed direct currents because it is a simple and effective method. A significant variety of alternating currents are frequently used in physiotherapy, where different waveforms and frequencies have different therapeutic effects on the subjected body parts.

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[126] See background chapter.

[127] Not pulsed galvanic currents can cause sustained muscle contraction beyond the onset, but they need to be of very high intensity. This special type of electric muscle stimulation is called 'galvanotetanus.' (Gillert, Rulffs and Boegelein 1995, p.62)

[128] This is a self-breaking circuit consisting of an inductor and a core operated switch, which causes an oscillation.

C.2.2.Mono- and biphasic stimulus

A few variations of direct pulsed currents exist. We have the simple mono-phasic type that in contrast to the biphasic type does not reverse its polarity. Biphasic currents share a similarity with alternating currents because of the aforementioned periodic polarity reversal. It has some variations in the timing of the polarity reversal that are illustrated in figure B.1. Biphasic stimulation has important advantages over mono-phasic stimulation in the physiologic effects on the wet body as is discussed below.

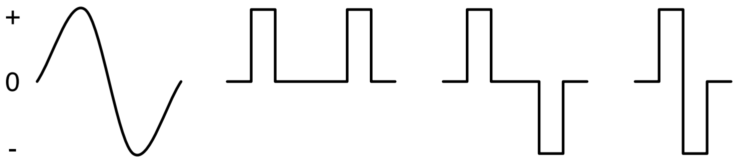

Figure B.1: Alternating and direct currents: faradic, mono-phasic, and two variations of biphasic currents.

C.3.Gradual muscle control: frequency, amplitude and duration

Fusing twitch quanta as we have seen, determines muscle tension and therefore the level of contraction. Gradual muscle control can be achieved by varying the frequency or rate of the action potentials or twitch quanta, which is how the nervous system controls muscle tension. (Reilly 1998, p.322)

Controlling the level of muscle contraction by externally applied electric impulses, is determined by two factors. One factor is the frequency of the pulsed direct currents, and the other the amount of applied electric energy. Frequency modulation of the electric impulses is similar in effect to varying the twitch quanta rate, which is how the brain controls the muscle's tension.

The second factor influencing muscle contraction is the amount of electric energy that passes along the nerve, i.e. changing amplitude and/or duration of the stimulating impulse. A muscle strength-duration relationship can be plotted for the biceps muscle showing stimulus current (<30 mA), pulse duration (0 to 0.8 ms) and muscle strength. (Figure B.2) The shorter the pulse width, the more current is needed to excite the nerve and hence contract the muscle. (Reilly 1998, p.126-129)

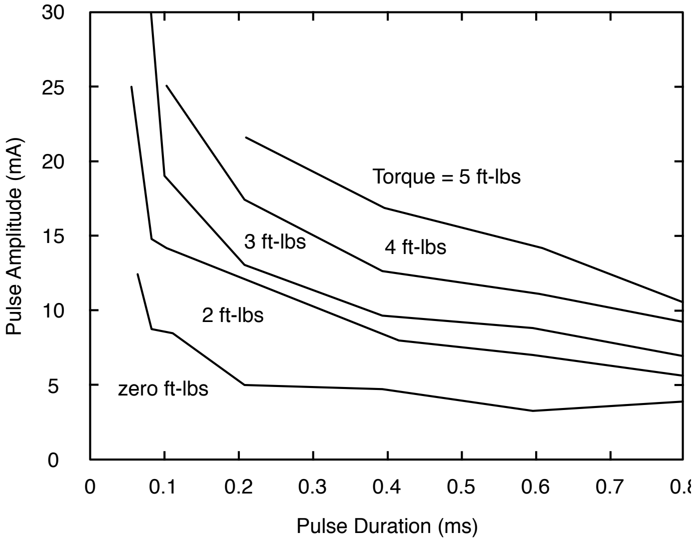

Figure B.2: Strength-duration curve for the surface stimulated biceps muscle. (Adapted from Reilly 1998)

Gradual external muscle control therefore is often a combination of varying frequency, amplitude and pulse width. Commercial TENS[129] devices that are offered for pain control usually allow to control these parameters. Another often used stimulus method is functional neuromuscular stimulation (FNS) that as the name implies is used in long term functional restoration of malfunctioning (denervated) muscles and is mostly used in rehabilitation.

FNS deals with the long term physical effects of electrically stimulating muscles, it focusses on fine control over frequency, amplitude and pulse width, as these factors can have a beneficial effect on muscle fatigue and muscle fiber recruitment. Details like this fall outside the scope of the research and will not be discussed.

C.4.Accessing the nerves

We have discussed the most important types of electric muscle stimulation for external muscle control and how the different parameters of the stimulating impulses allows gradual, smooth muscle contraction. The next important issue is how these impulses can be externally applied.

C.4.1.Direct and indirect stimulation

Somehow the motor nerves need to be accessed in order to apply the stimulating electric currents. Fortunately, motor nerves are anatomically located just beneath the skin and can be

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[129] Transcutaneous Electrical Nerve Stimulation; i.e. through the skin stimulation.

accessed directly or indirectly. The direct method requires the use of skin penetrating electrodes (needles or very thin wires) or by surgical implants of for example a cuff electrode.

A nonintrusive, indirect and therefore more readily applicable way of accessing the nerves, is by placing electrodes on the surface of the skin and let a current flow between them. In view of the fact that one of the goals of the research is to have volunteers participating in future artworks, non-intrusiveness, ease of use and comfort of the stimulating currents are important issues. Consequently, the research will abstain from intrusive methods and will use surface applicable electrodes and non-pain inflicting stimulating currents.[130]

This is not to say that direct nerve stimulation has no advantages, direct access to the nerves is of course more precise than inducing currents over a larger surface area, which has the inherent ‘risk’ of stimulating other muscles or nerves. Nonetheless, as my work has shown, quite accurate results can be achieved by simple means such as transcutaneous multiplexed mono-phasic stimulus.

C.4.2.Surface electrodes, placement and size

Duchenne already found as early as 1831 that by moving a small moistened cloth covered electrode over the skin, muscular contractions were most easily obtained at hyperexcitable locations that he called points of election. Remak and Ziemssen subsequently found these points are the sites where the nerve trunk terminates in muscle end-plates, the so called motor points. Coers (1955) then showed that the highest concentration of motor end-plates are located just beneath the skin, which attributes to their easy excitability by surface electrodes. (Reilly 1998, p.314) Figure B.3 shows the nerve ending in the motor point of the muscle, and illustrates current flow and density in the underlying tissue.

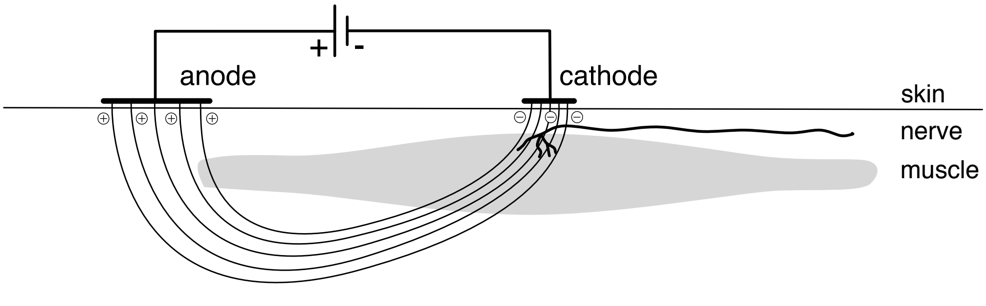

Figure B.3: Mono-polar stimulus, showing the effect of electrode size on current density and hyper- and depolarizing of the underlying tissue. (Adapted from Gillert, Rulffs and Boegelein 1995)

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[130] Issues of comfort will be discussed below.

As convention tells us, electric current flows from a site with an excess of electrons, the anode, to the cathode, a site with a lack of electrons, thereby passing through an intermediate conductive medium. An electron deprived cathode, depolarizes the underlying tissue, which increases the excitability of the nerves, and for this reason is placed directly above the motor point. The electron saturated anode, hyperpolarizes the underlying tissue, which eases the excitability of the nerves. Because of these polarization effects of direct currents, correct placement on the body of the cathode and so called “indifferent” anode is essential. (Gillert, Rulffs and Boegelein 1995, p.42,43)

Duchenne noted that using as small as possible electrodes excites the muscles at the motor point the best. Larger electrodes on the contrary, reduce the current density at the location, which eases excitability. Hyper- and depolarizing effects of the electrode’s size and polarization, can be put to practical use; a small cathode is placed over the excitable motor point and a large “indifferent” anode is placed at a site where no excitation is desired. (Figure B.3)

The use of small surface electrodes has one major practical drawback which is caused by the contraction of the stimulated muscle itself. The contracting muscle can cause a displacement of the skin attached electrode away from the motor point, reducing its effectivity to the point where, in rare cases, the muscle completely relaxes. In case of extreme electrode shifting, it can result in an alternating relaxation/contraction condition; i.e. muscle oscillation.

Making surface electrodes as small as possible is therefore not the most optimum solution, typically a balance needs to be found between accuracy and motor point coverage. The Encoding chapter on the development of a muscle stimulus device shows from practice what electrode size was found to work most effectively.

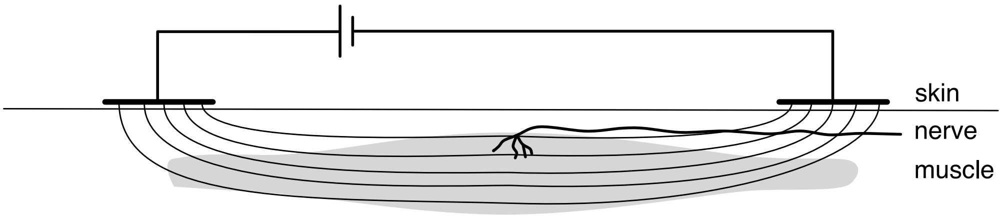

Figure B.4: Bipolar stimulus, longitudinal current flow. Biphasic stimulus on similar sized electrodes, it is often used with denervated muscles. (Adapted from Gillert, Rulffs and Boegelein 1997)

The mono-polar electrode method is used with mono-phasic stimulation currents. The other stimulus method is the bipolar setup, that is primarily used with biphasic stimulation as is illustrated in figure B.4. Electrodes have to be placed along the length of the muscle, so current flows longitudinally. The bipolar, biphasic method has the (dis)advantage that polarization effects are insignificant.

Both mono-polar and bipolar methods are discussed in the Encoding chapter on their practical applicability in multi-muscle electrical stimulation of the face.

C.5. Physiological and psychological effects of electric muscle stimulation: safety and comfort

Passing electric currents through wet human tissue has its own set of problems. While the operation of the human body is largely dependent on electricity for its control system, it has none of the problems discussed below, because the nervous control system is signal instead of current based.

Problems arise when electric current is flowing through wet tissue as is happening with external electrical stimulation. It can cause chemical decomposition by electrolysis, tissue damage by high currents, ventricular fibrillation of the cardiac muscle and excitation of pain receptors in the skin. These issues warrant a deeper understanding because the human body and electricity can have a problematic, and potentially fatal, relationship.

C.5.1. Electrolysis

The human body is a wet medium containing a mixture of salts making it a fine electrolyte. When an electric current flows between two electrodes, the conductive medium is ionized causing a chemical decomposition; tissue at the anode becomes acidic (HCL) and the cathode alkalic (NaOH) with pH values reaching nine or more (Gillert, Rulffs and Boegelein 1995, p. 61). Ions move with a speed of approximately a few millimeters an hour towards the electrodes. If this process is left to continue, a concentration of chemical agents at the skin lowers its resistance, current increases and damage to the epidermis can occur. Gillert writes: “If the patient complains about a burning feeling at the location of the cathode, stop the treatment.” and “Bei der stabilen Punktgalvanisation vermeidet man die Verätzung dadurch, daß man sofort mit der Stromstärke heruntergeht, sobald der Patient an der Elektrode ein Hitzegefühl oder gar ein Brennen verspürt.” [131](Gillert 1977, p.20,21)

Electrolysis effects of mono-phasic stimulus currents are not problematic because of the very short pulse durations. In electronic design, however, care should be taken that no small continuous direct (leakage) currents are flowing through the body.[132] Biphasic or alternating currents are ideal in this respect as the polarity reversal completely prevents electrolysis.

C.5.2.Physical destruction

Passing electrical currents through the body is not something one wants to take too lightly, because application of high currents can be physically destructive. In extreme cases, current density levels at the electrode location can lead to skin and tissue burn, effectively destroying tissue functionality. (Bridges et al., 1985) It can also lead to a more subtle loss of functionality when nerves are overexcited (“zapped”), impairing their normal operation as discussed in the background chapter.

A different kind of damage can occur when applying sudden high currents, which was evidenced by Duchenne: “His head executed a movement and inclination so forcible that the patient felt something crack, and had acute pain in the neck.” (Duchenne 1871, p.80) The uncontrolled and strong stimulation of the sternomastoid muscle was so powerful that the muscle’s tendon came loose from the bone.

C.5.3.Cardiac and Respiratory arrest

The worst case of destruction is the loss of life itself. In many cases the cause of death by electrocution is not by physical destruction of bodily tissue, but by cardiac arrest, leading to an oxygen deprived brain. The cause of heart failure is the hypersensitivity of the cardiac muscle to very small currents (< 300 µA) passing directly through the heart (intracardiac). (BS 60601-1 1990) An erratic condition called *ventricular fibrillation* occurs, a functional loss of the heart’s capacity to pump blood through the body. This condition can only be corrected by passing very high currents straight through the heart; the process known as *defibrillation*. Irreversible damage to the oxygen deprived brain starts to occur after only 3 to 4 minutes, so immediate defibrillation action should be taken.

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[131] In early experiments, I have experienced the electrolysis effects himself, subjectively put; extremely painful.

[132] In electronic design of electro stimulus devices, a direct current blocking capacitor is sufficient to prevent electrolysis.

Respiratory arrest is another hazard of electric current flow, which can be caused by a limb-to-limb prolonged current of 20 to 30 mA that passes through the respiratory muscles. Switching off the current will resume normal breathing. (Bridges et al. 1985, p.11)

Safe operation of muscle stimulus devices therefore requires control over safe current levels and an avoidance of (uncontrolled) conditions that can cause (very small) currents from flowing through the heart or respiratory muscles.

C.5.4.Safety precautions

Application of electrical currents to the human body, requires utmost attention as it has the capacity to be lethal. We just discussed a number of these issues, in this section we look into safety measures to prevent anything unpleasant to happen.

Current path

The worst case of harmful electrical current application to the human body, is the condition of cardiac arrest. It can be caused by even extremely small currents passing through the heart region. For this reason, at all times, the current flow through the human body should be carefully reviewed before the application of electrodes. A hand to hand current path, for example, is a reliable way to send electrical currents through the heart region. Although current density decreases in body mass, current levels at particular low impedance tissue can cause damage (cardiac arrest).

Safe current levels

Safe current levels for electronic stimulation of the muscles is a very complex issue, an amalgam of body impedance, frequency, pulse duration and current levels. The reader is referred to the appropriate literature to learn about these issues and the intriguing *electrocution equation.* (Bridges et al. 1985, p.284)

However, the British Standards Institution provides clear guidelines for the design of medical devices. It is safe and convenient to follow the recommendations made in these documents; safe operating currents should remain below 15 mA. (BS 60601-2 2001)

Higher current levels can be safe, but require a thorough understanding of the above mentioned issues. Neuromuscular stimulation of the facial muscles does not require higher currents than the recommendation, therefore is a safe guideline.

Electrolysis

Electronic muscle stimulus devices, should be designed with a direct current blocking facility, because the resultant electrolysis of direct current flow can cause very unpleasant damage to the epidermis. Two adequate solutions are available; a DC blocking capacitor in the current circuit or the use of biphasic currents.

Galvanic isolation

Electrode placement, as discussed, is crucial in controlling the current path. Unforeseen current pathways can occur when the stimulating circuit is not electrically isolated from other electrical circuits in the environment. A stimulus device need to be galvanically isolated, so no inadvertent currents can flow from or to the human body, for example by touching other electric appliances. Typically, muscle stimulus devices are operated in a closed circuit with its own power source; i.e. a battery.

If the device is controlled by a host computer, the communications channel should have galvanic separation as well; e.g. an opto-isolated MIDI interface or wireless channel (Wifi or Bluetooth).

Environmental conditions

Working with humans has the potential of inadvertent conditions to occur in the working environment. This may cause a loss of concentration, for example at the time of calibrating muscle stimulus currents. It can result in the unintended application of too high, unpleasant current levels which can cause unpleasant cramp or worse. We already discussed the extreme case of Duchenne, where sudden uncontrolled high current levels caused a tendon to come lose from the bone.

In any condition, the operator of a stimulus device should be cautious about unpredictable conditions and contemplate the entire situation before applying electrical currents to the human body.

Ethical approval

Working with electricity and the human body in an institutional context may require compliance to health and safety regulations and consent of the voluntary subjects. An increasing number of (educational) institutions, even in the arts, require a risk assessment and participation in an ethical approval procedure. Appendix G refers to the risk assessment and consent paper work that I developed for this research at Sheffield Hallam University.

C.5.5.Psychological effects: issues of (dis)comfort

In electro stimulation, the skin, consisting of a layer of dead cells, is a high resistance barrier that needs to be overcome. The skin also embeds pain receptors (nociceptors) that report a variety of potentially tissue damaging events, such as mechanical, thermal or chemical changes to the central nervous system and the brain. A side effect of transcutaneous stimulation of the motor nerves is the (unfortunate) excitation of the pain receptors. It leads to 'false' reports of 'pain,' a typical feeling of discomfort that Gillert describes as "Elektrisiergefühl," the sensation of the flow of electrical current (Gillert 1977, p.25). Perhaps this typical sensation might be described as 'artificially induced pain reception' or even 'artificial pain,' [133] but the fact is, that in practice this effect can be reduced by the proper choice of pulse width of the stimulating impulses.

To explain how this works, we need to take a closer look at a cross section of a typical skin construct. (Figure B.5) The layering of the different types of tissue, electrically acts as a capacitance, which coupled with the resistance of the tissue itself, results in an electrical impedance. It is expressed in the picture as an electrical diagram. (Gillert 1995, p.30) The epidermis builds a high resistance (thousands of ohm) for direct currents, while the muscular tissue has a constant low resistance of about 1KΩ.[134] Given the electric properties of the

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[133] It is noteworthy to mention the therapeutic use of electric stimulation as a means to relief pain.

[134] Skin impedance is gender dependent; women have a thinner skin and therefore have a lower skin impedance. Women for this reason are more sensitive to electrical stimulation than men, an issue performers should take into account.

skin's capacitance, higher frequencies of the stimulating current, pass through the skin with less resistance than lower frequencies. As a result, skin embedded nociceptors become less excited or not at all. Consequently, alternating currents of high frequency are experienced as pleasurable. (Gillert 1995, p.32,84,94)

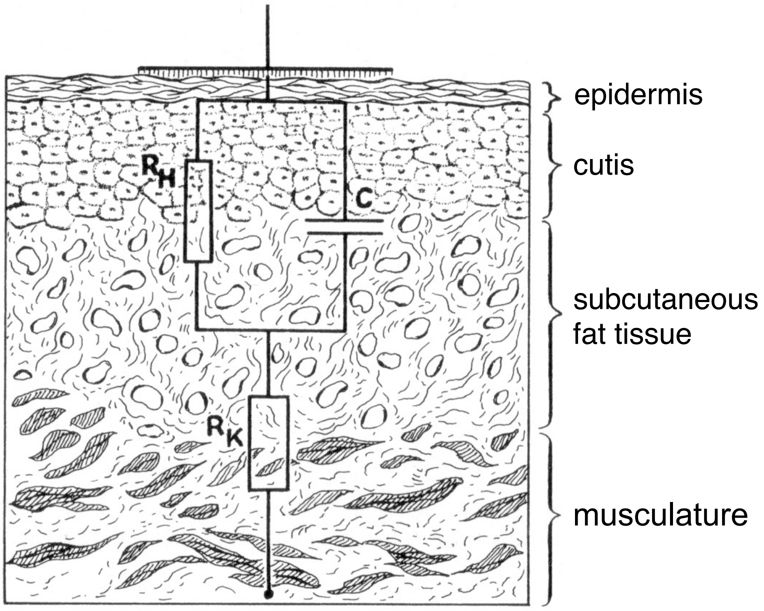

Figure B.5: Cross section of epidermis and deeper tissues with a functional electric replacement diagram. (Taken from Gillert 1995)

It further turns out that impulse currents with very steep curves, essentially square wave pulses containing high frequency harmonics and short pulse widths (< 1 ms) have the same effect and are experienced as less or not irritating at all. Otto May in an article in 1911 already mentions that the aforemetioned *Leduc currents,* were found to be less painful. (May 1911)

C.5.6.Side effects of electro stimulation: eye flicker, galvanic taste

A side effect of stimulating the facial muscles is eye flicker, which results from the parasitic stimulus of the optic nerve. Colorful flashes can be 'seen' as if one looks into a flash light, but without the after image, eye flicker is considered harmless.

Another parasitic side effect is the experience of "galvanic taste" as if one licks a metal object (Gillert 1977 p.26,27). I have also experienced the triggering of "artificial toothache," but like the above effects seem to have disappeared with decreased stimulus pulse width and the blocking of continuous currents.

Galvanic skin response is another issue of importance, especially in stage performance or when working with inexperienced subjects. Anxiety affects the sweat glands in the skin reducing its impedance, which as a result increases the current level of the stimulus. On stage, this can have (un)intentional dramatic effects as the muscular contractions can be more powerful than when calibrated back stage.[135]

C.5.7.Some thoughts on the performability of electric performance art

As comfort of electrical stimulation on the human body plays such an important role in the performability of electric performance art, a few notes are necessary. Although the application of electrical impulses on the body, due to reasons explained, can trigger sensations of pain or irritation, actually enduring these sensations might not be as hard as it may seem. Pain is a difficult phenomenon to define, that has both a physiological and psychological dimension to it. At the onset of some nociceptive event, the brain immediately gets involved in priority reassessment processes in order to eliminate the source of the perceived threat.

Neurophysiologist Jonathan Cole, who specializes in the human face, quoted Descartes in conversation with Burman on this issue: “The body has an obstructive effect on the soul. We are aware of this phenomenon in ourselves, when we prick ourselves with a needle or some sharp instrument: the effect is such that we cannot think of anything else... The body is always a hindrance to the mind in its thinking.” (from Cottingham 1976, p.8) (Cole 2000)

Marvin Minsky in “The Society of Mind” words it like this: “Somehow, the pain receptors (edited) disrupt our concerns with long-term goals—thus forcing us to focus on immediate problems, perhaps by transferring control to our lowest-level agencies.” (Minsky 1985, p.37)

These two quotations point to the psychological effect of pain inducing events, and the brain’s response to eradicate the source of the potentially harmful event. Because of the all encompassing nature of the brain’s occupation with pain sensations, the performer seems to be put in a mental condition that eases to focus on the immediate task at hand. This might

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[135] If a constant current source is used for the stimulus electronics, galvanic skin response is automatically compensated. More in the Encoding chapter on electronic design.

also be the reason many performance art pieces where a level of pain or physical discomfort is involved often are such serene experiences.[136]

Summary

Electrical stimulation of the human body is a large topic that within the scope of this research has only been glanced upon. It gave practical insight in the most important issues involved in external control of the facial muscles; types of electric impulses, electrodes, safety and comfort.

These aspects have been thoroughly covered for the development of a new generation computer controlled stimulus device, that subsequently has been deployed for the research's experiments and demonstrations.

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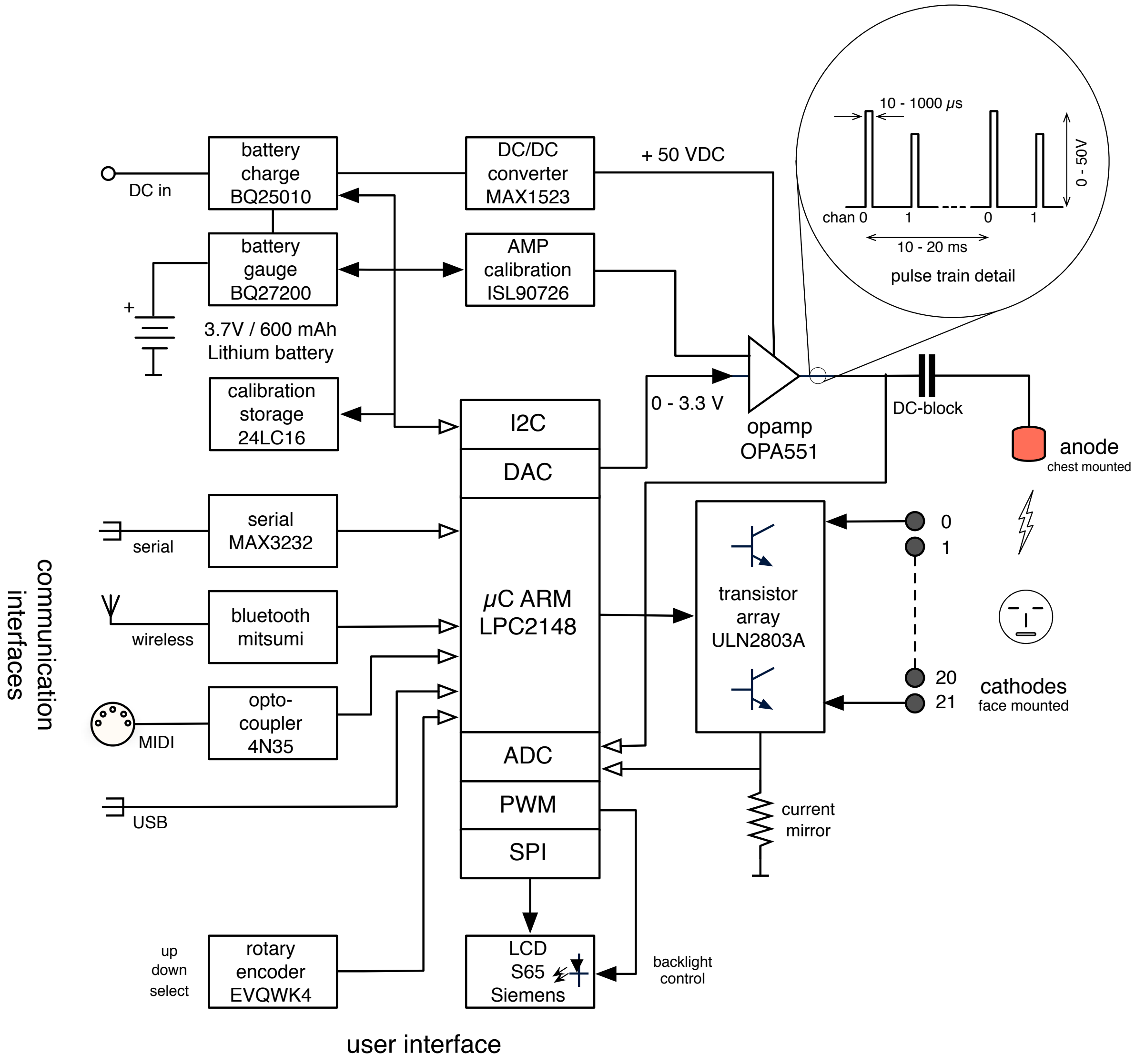
[136] I am aware this reasoning potential breaks the myth of this type of performance art as being ultimately hard to do, needing much courage, but from my own experience cannot conclude otherwise.

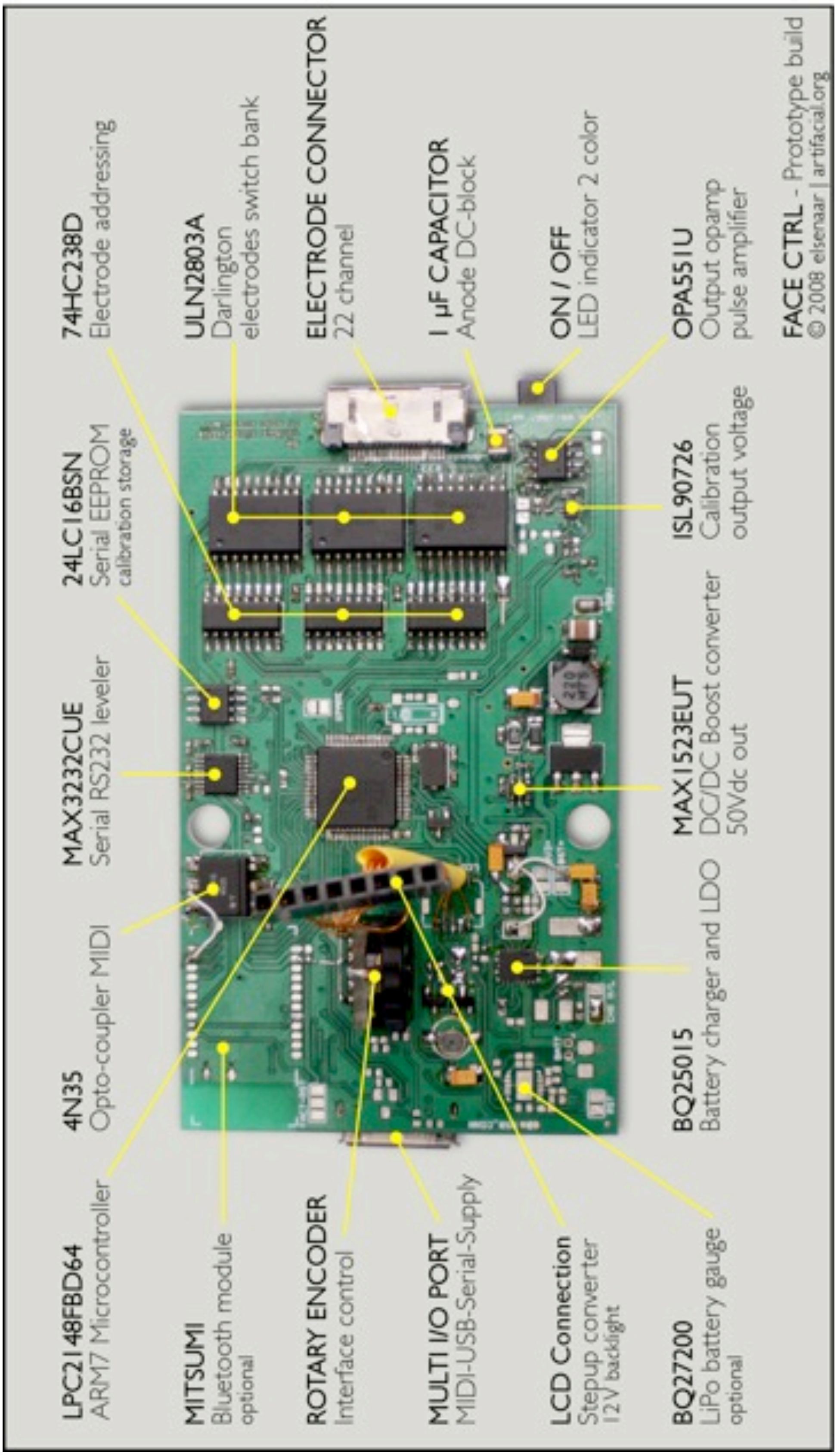
Appendix D

D.Facial Control Device

D.1.Electronic Block Diagram



D.2.Assembled Prototype



Appendix E

E. Facial Muscles

E.1. Facial Muscle Map

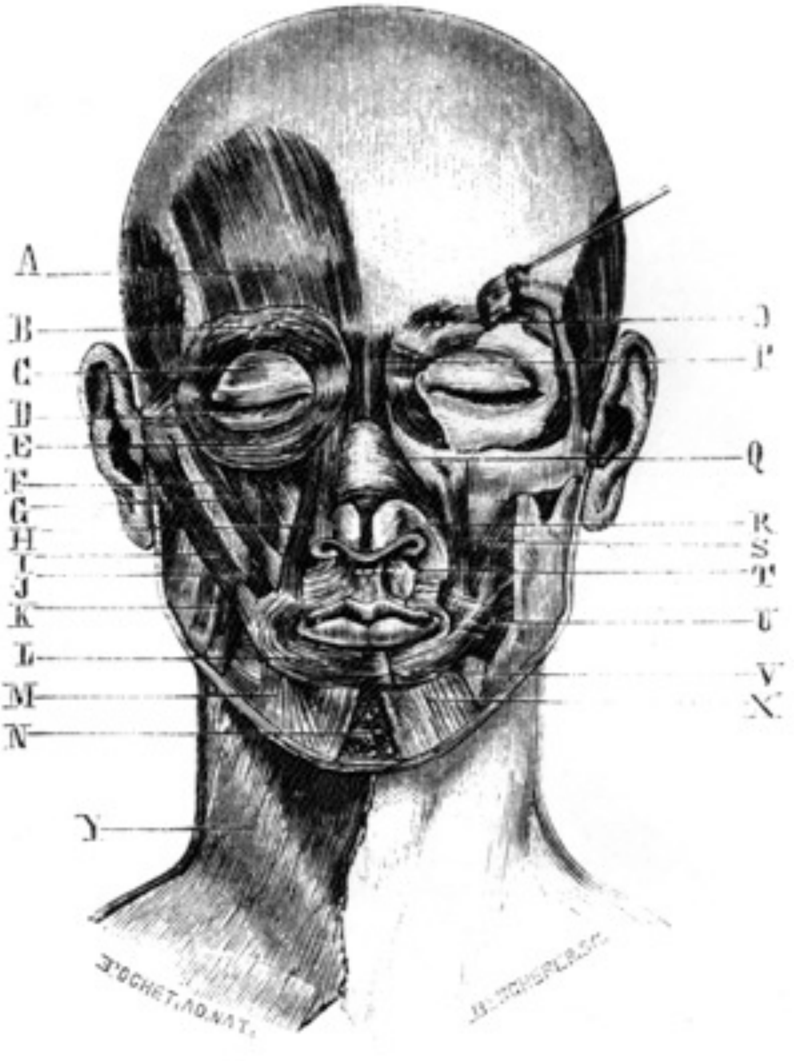


Plate 1: An anatomical preparation of the muscles of the face. A. *m. frontalis*, muscle of *attention*; B. superior part of *m. orbicularis oculi*, muscle of *reflection*; C, D. palpebral part of *m. orbicularis oculi*, muscle of *scorn* and complementary to *crying*; E. inferior part of *m. orbicularis oculi*, muscle of *kindness* and complementary to *overt joy*; F. *m. zygomaticus minor*, muscle of *moderate crying* and of *affliction*; G. *m. levator labii superiorus*, muscle of *crying*; H. *m. levator labii superiorus alaeque nasi*, muscle of *sniveling*; I. *m. zygomaticus major*, muscle of *joy*; K. *m. masseter*; L. *m. orbicularis oris*; M. *m. depressor anguli oris*, muscle of *sadness* and complementary to *aggressive feelings*; N. *m. mentalis*; O. *m. corrugator supercilii*, muscle of *pain*; P. *m. procerus*, muscle of *aggression*; Q. transverse part of *m. nasalis*, muscle of *lasciviousness* and *lubricity*; R. dilator portion (pars alaris) of *m. nasalis*, complementary muscle to passionate expressions; S. *m. caninus*; T. *m. depressor septi*; U. *m. buccinator*, muscle of *irony*; V. deep fibers of *m. orbicularis oris*, which are continuous with *m. buccinator*; X. *m. depressor labii inferiorus*, complementary muscle to *irony* and of *aggressive passions*; Y. *m. platysma*, muscle of *fear*, of *terror* and complementary to *anger*.

The facial muscles and their relation to the emotions. (Duchenne 1862, p.45).

E.2.Facial Nerve Map

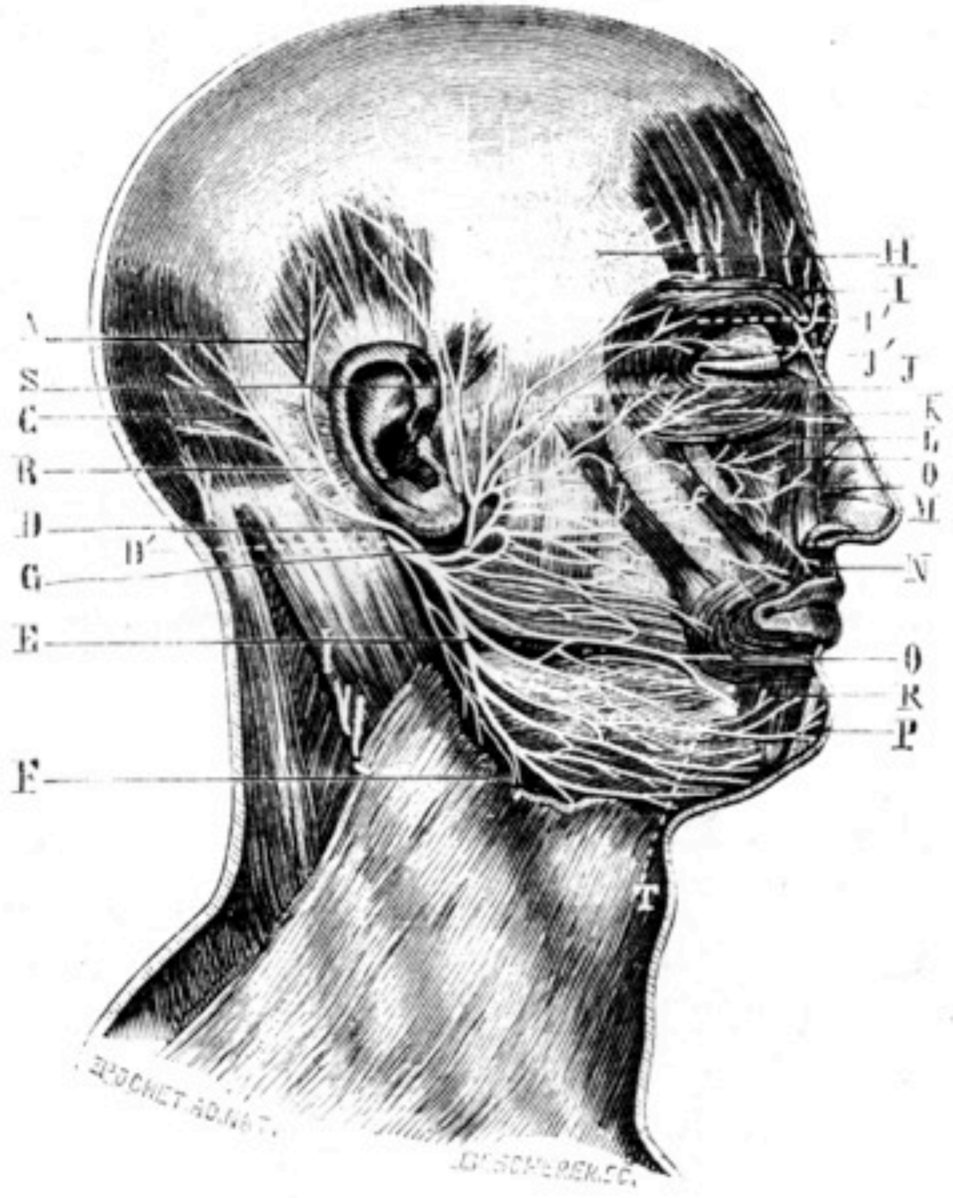


Plate 2a: An anatomical preparation of the motor nerves of the face (of the VIIth nerve). A., B. motor branches to *m. auricularis superior and posterior;* C. motor branch to the occipital belly of *m. occipitofrontalis;* D. turn of the facial nerve at its exit from the facial canal; E. cervicofacial branch; F. motor branch to *m. platysma;* G. temperofacial branch; H. motor branch to *m. frontalis;* I. motor branch to *m. corrugator supercilii;* I′. motor branch to the outer superior part of *m. orbicularis oculi;* J. motor branch to the inferior part of the palpebral portion of *m. orbicularis oculi;* J′. motor branch to the superior part of the palpebral portion of *m. orbicularis oculi;* K. motor branch to the inferior part of *m. orbicularis oculi;* L. motor branch to *m. levator labii superiorus alaeque nasi;* M. motor branch to the transverse part of *m. nasalis;* N., O. motor branch to *m. orbicularis oris;* P. motor branch to *m. mentalis;* Q. motor branch to *m. levator labii superiorus;* R. motor branch to *m. depressor labii inferiorus;* S. auriculotemporal branch of the trigeminal nerve; T. motor nerves to the inferior portion of *m. orbicularis oris, m. depressor labii inferiorus, m. mentalis,* and *m. depressor anguli oris.*

The 7th cranial motor nerve designation of the face. (Duchenne 1862, p.46)

E.3.Facial Action Coding System

AU #	FACS Name	Muscular Basis	AU #	FACS Name	Muscular Basis
1	Inner Brow Raiser	Frontalis, Pars Medialis	20	Lip Stretcher	Risorius
2	Outer Brow Raiser	Frontalis, Pars Lateralis	22	Lip Funneler	Orbicularis Oris
4	Brow Lowerer	Depressor Glabellae; Depressor Supercilli; Corrugator	23	Lip Tightner	Orbicularis Oris
5	Upper Lid Raiser	Levator Palpebrae Superioris	24	Lip Pressor	Orbicularis Oris
6	Cheek Raiser	Orbicularis Oculi, Pars Orbitalis	25	Lips Part	Depressor Labii, or Relaxation of Mentalis or Orbicularis Oris
7	Lid Tightener	Orbicularis Oculi, Pars Palebralis	26	Jaw Drop	Masseter; Temporal and Internal Pterygoid Relaxed
8	Lips Toward Each Other	Orbicularis Oris	27	Mouth Stretch	Pterygoids; Digastric
9	Nose Wrinkler	Levator Labii Superioris, Alaeque Nasi	28	Lip Suck	Orbicularis Oris
10	Upper Lip Raiser	Levator Labii Superioris, Caput Infraorbitalis	38	Nostril Dilator	Nasalis, Pars Alaris
11	Nasolabial Furrow Deepener	Zygomatic Minor	39	Nostril Compressor	Nasalis, Pars Transversa and Depressor Septi Nasi
12	Lip Corner Puller	Zygomatic Major	41	Lid Droop	Relaxation of Levator Palpebrae Superioris
13	Cheek Puffer	Caninus	42	Slit	Orbicularis Oculi
14	Dimpler	Buccinnator	43	Eyes Closed	Relaxation of Levator Palpebrae Superioris
15	Lip Corner Depressor	Triangularis	44	Squint	Orbicularis Oculi, Pars Palpebralis
16	Lower Lip Depressor	Depressor Labii	45	Blink	Relaxation of Levator Palpebrae and Contraction of Orbicularis Oculi, Pars Palpebralis
17	Chin Raiser	Mentalis	46	Wink	Orbicularis Oculi
18	Lip Puckerer	Incisivii Labii Superioris; Incisivii Labii Inferioris			Table D.1

AU #	FACS Name	AU #	FACS Name
19	Tongue Out	33	Cheek Blow
21	Neck Tightener	34	Cheek Puff
29	Jaw Thrust	35	Cheek Suck
30	Jaw Sideways	36	Tongue Bulge
31	Jaw Clencher	37	Lip Wipe
32	Lip Bite		Table D.2

E.4.The Electro-Expressive Muscles

Access Point	AU #	Muscle Action	Muscular Basis	Duchenne's Muscles of Emotion
0	n/a	Inner brow raiser, raises medially and lowers laterally: brow tilt	Orbicularis oculi, Pars orbitalis	Reflection
1	2	Outer brow raiser	Frontalis, Pars Lateralis	*not identified*
2	1	Brow raiser	Frontalis, Pars Medialis	Attention
3	(4)	Inner brow depressor	Procerus *1	Aggression
4	12	Lip corner puller, bulging the cheeks	Zygomatic major	Joy
5	14	Dimpler	Buccinator	Irony
6	15	Lip corner depressor	Depressor anguli oris	Sadness
7	16	Lower lip depressor	Depressor labii inferioris	Complementary to Irony and Aggression
8	26	Jaw drop	Platysma *2	part of aggression

Note:

1) Although a number of muscles are involved in the lowering of the brow, Duchenne attributed the Procerus muscle to this effect, while Ekman and others also designate Depressor supercilii and Corrugator supercilii to this movement of the brow (AU 4), for simplicity Duchenne is followed.

2) As relaxation of an already neurally contracted muscle (Masseter) cannot be revoked externally, the lowering of the jaw is defined by the contraction of the Platysma.

3) Figure 3.5 illustrates the electro-expressive muscles in a diagram.

Appendix F

F. Experimental Data

F.1. Facial Muscle Speed (no bias)

Tabular data of the facial muscle speed measurement with no bias stimulus level. On and Off represent video frame positions. Averages have anomalies that are indicated in the notes removed.

Experiment method. muscle. take	Stimulus Level	On start	On max	time (ms)	average 3 exp.	Off start	Off off	time (ms)	average 3 exp.	note
1.00	**half**	20	34	560		69	82	520		
	full	120	131	440		174	188	560		
	overshoot	223	230	280		273	283	400		
1.01	**half**	20	34	560		70	79	360		
	full	122	131	360		171	180	360		
	overshoot	221	229	320		272	285	520		
1.02	**half**	19	33	560	560	71	81	400	440	
	full	122	132	400	400	173	183	400	460	
	overshoot	224	232	320	307	273	283	400	460	
1.10	**half**	20	29	360		72	91	760		off time unreliable: glitch
	full	123	135	480		173	189	640		
	overshoot	226	235	360		276	293	680		
1.11	**half**	20	30	400		70	83	520		
	full	122	133	440		171	183	480		
	overshoot	221	229	320		272	285	520		
1.12	**half**	20	29	360	373	69	83	560	613	
	full	120	130	400	440	171	184	520	547	
	overshoot	221	231	400	360	273	287	560	587	
1.20	**half**	20	30	400		71	81	400		
	full	121	126	200		172	184	480		
	overshoot	222	229	280		273	285	480		eye blink troubles observa
1.21	**half**	20	28	320		72	82	400		
	full	123	131	320		173	184	440		
	overshoot	225	233	320		275	288	520		
1.22	**half**	20	28	320	347	70	79	360	387	
	full	121	131	400	307	171	183	480	467	
	overshoot	221	230	360	320	271	282	440	480	
1.30	**half**	20	38	720		70	86	640		off time unreliable: freeze
	full	121	133	480		171	182	440		

Experiment method. muscle. take	**Stimulus Level**	**On start**	**On max**	**time (ms)**	**average 3 exp.**	**Off start**	**Off off**	**time (ms)**	**average 3 exp.**	**note**
	overshoot	221	233	480		271	283	480		
1.31	**half**	20	32	480		70	82	480		
	full	120	129	360		170	181	440		
	overshoot	220	235	600		271	281	400		
1.32	**half**	20	38	720	640	70	79	360	493	
	full	120	130	400	413	171	184	520	467	
	overshoot	221	233	480	520	271	282	440	440	
1.40	**half**	20	35	600		68	81	520		
	full	118	130	480		171	185	560		
	overshoot	222	232	400		272	282	400		
1.41	**half**	20	35	600		70	82	480		
	full	121	133	480		171	183	480		
	overshoot	223	233	400		273	283	400		
1.42	**half**	20	38	720	640	71	81	400	467	
	full	122	131	360	440	173	182	360	467	
	overshoot	224	237	520	440	273	281	320	373	
1.50	**half**	20	31	440		71	84	520		
	full	121	128	280		171	183	480		
	overshoot	222	232	400		271	285	560		400 on time dismiss: not f
1.51	**half**	20	29	360		70	83	520		
	full	119	126	280		171	185	560		
	overshoot	222	236	560		272	287	600		
1.52	**half**	20	31	440	413	70	81	440	493	
	full	119	127	320	293	170	183	520	520	
	overshoot	220	238	720	560	271	289	720	627	
1.60	**half**	20	35	600		71	87	640		
	full	122	133	440		173	188	600		
	overshoot	224	235	440		275	292	680		
1.61	**half**	20	35	600		70	88	720		
	full	121	132	440		173	189	640		
	overshoot	224	235	440		273	287	560		
1.62	**half**	20	35	600	600	71	86	600	653	
	full	123	131	320	400	173	186	520	587	
	overshoot	224	232	320	400	274	285	440	560	
averages	half				510				484	
(mean)	full				385				499	
	overshoot				423				502	action speed; most visible
										movement
				facial muscle speed (no bias)						

F.2. Facial Muscle Speed (with bias)

Experiment method. muscle. take	**Stimulus Level**	**On start**	**On max**	**time (ms)**	**average 3 exp.**	**Off start**	**Off off**	**time (ms)**	**average 3 exp.**	**note**
2.00	**half**	3	18	600		80	96	640		some freeze frames ~50
	full	114	126	480		166	183	680		
	overshoot	216	234	720		276	281	200		
2.01	**half**	4	10	240		54	76	880		frame 4-10 freeze
	full	104	115	440		155	172	680		
	overshoot	209	223	560		261	274	520		
2.02	**half**	4	20	640	493	54	72	720	760	
	full	105	115	400	440	155	175	800	680	
	overshoot	206	216	400	560	257	271	560	360	
2.10	**half**	4	15	440		53	68	600		off state weird glitch
	full	104	115	440		153	166	520		
	overshoot	206	216	400		256	268	480		
2.11	**half**	5	16	440		54	65	440		
	full	106	116	400		156	165	360		
	overshoot	209	222	520		259	271	480		
2.12	**half**	3	13	400	427	54	65	440	493	
	full	104	115	440	427	155	167	480	453	
	overshoot	208	221	520	480	257	275	720	560	
2.20	**half**	4	13	360		58	77	760		
	full	108	118	400		159	171	480		
	overshoot	211	223	480		261	275	560		
2.21	**half**	4	10	240		57	67	400		
	full	108	122	560		159	169	400		
	overshoot	209	220	440		260	271	440		
2.22	**half**	3	11	320	307	53	63	400	520	
	full	105	117	480	480	155	166	440	440	
	overshoot	208	218	400	440	258	271	520	507	
2.30	**half**	4	33	1160		55	87	1280		
	full	106	125	760		157	178	840		
	overshoot	210	230	800		260	275	600		
2.31	**half**	3	31	1120		53	68	600		
	full	104	117	520		155	165	400		
	overshoot	207	222	600		256	272	640		
2.32	**half**	3	29	1040	1107	53	64	440	773	
	full	105	121	640	640	155	162	280	507	
	overshoot	205	223	720	707	256	265	360	533	
	half	5	16	440		54	62	320		

Experiment method. muscle. take	**Stimulus Level**	**On start**	**On max**	**time (ms)**	**average 3 exp.**	**Off start**	**Off off**	**time (ms)**	**average 3 exp.**	**note**
2.40	**full**	105	115	400		155	164	360		
	overshoot	206	217	440		256	268	480		
2.41	**half**	4	15	440		53	68	600		
	full	105	115	400		155	166	440		
	overshoot	208	219	440		257	266	360		
2.42	**half**	3	14	440	440	53	63	400	440	
	full	104	115	440	413	155	165	400	400	
	overshoot	205	217	480	453	256	268	480	440	
2.50	**half**	4	20	640		54	66	480		
	full	104	114	400		156	168	480		
	overshoot	206	216	400		256	266	400		
2.51	**half**	4	18	560		56	73	680		
	full	105	119	560		157	171	560		
	overshoot	208	220	480		257	266	360		
2.52	**half**	4	20	640	613	53	64	440	533	
	full	104	114	400	453	156	169	520	520	
	overshoot	205	216	440	440	255	266	440	400	
2.60	**half**	4	25	840		54	80	1040		
	full	104	120	640		155	188	1320		
	overshoot	207	221	560		258	285	1080		
2.61	**half**	3	22	760		54	80	1040		
	full	105	121	640		155	186	1240		
	overshoot	207	221	560		258	282	960		
2.62	**half**	4	16	480	693	53	69	640	907	
	full	105	122	680	653	156	176	800	1120	
	overshoot	206	220	560	560	257	285	1120	1053	
averages	half				600				598	
(mean)	full				501				594	
	overshoot				520				560	action speed; most visible
										movement

facial muscle speed (with bias)

Appendix G

G.Ethical approval

Working with electricity and the human body in an institutional context may require compliance to health and safety regulations and consent of the voluntary subjects. The procedure usually involves a risk assessment, approval by the ethical commission of the institute and properly informed consent by the volunteering participants.

On request, I can provide the prepared risk assessment, participant information sheet and consent forms that were required for this research. If the reader likes to receive a copy, please send me an email at arthur@artifacial.org.

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