DEPARTMENT
OF PHYSICS

NON-VERBAL COMMUNICATION WITH PHYSIOLOGICAL SENSORS: THE AESTHETIC DOMAIN OF WEARABLES AND NEURAL NETWORKS

DESIGNING TECHNOLOGIES FOR EXPRESSIVE, SPEECHLESS DIALOGUE

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Master in ⟨Creative Computing⟩

DOCTORATE IN BIOMEDICAL ENGINEERING

NOVA University Lisbon
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Introduction

In the process of any given interaction, humans will naturally reveal a vast arrangement of signals independently from speech. Physical traits such as posture, gait and eye-contact come under the social phenomenon known as Non-verbal behaviours. Other examples of non-verbal cues commonly studied in the literature include facial expressions and tone of voice [8], assuming a kind of social cue that's observable during a conventional human-human exchange when given deliberate attention. However, we should also take into account the changes that take place inside of the body, being those not so easily perceived without way of technological intervention.

Affective Computing, and specifically the combination of physiological sensing and cognitive frameworks has been established for over two decades [38], securing prospects for developing emotionally-informed systems. A significant progression in this field can be conclusive of using state-of-the-art Machine Learning (and Deep Learning) methods to interpret large-scale datasets, achieving honourable breakthroughs in view of emotion recognition studies [6]. Such systems tend to operate according to linguistic descriptors of universal emotions. We recognise however, that these discrete representations become less meaningful when perceived in lack of contextual information. An emerging area of research considers the role of interactive systems for sharing of physiological activity between it´s users, enhancing connectedness by way of anatomical transparency [31]. The resulting artefacts tend to utilise raw forms of data representation, disregarding emotional interpretation. Simultaneously, embodied sensor technology has been incorporated in to creative practices, commonly as a means to capture emotional qualities of bodily gestures during performance, and then being able to transmit this information to a third-person perspective [15].

Aesthetic representations have been incorporated into a wide range of user-centred technologies, observed by the broader vision of third-wave Human-Computer Interaction, through the comprehension that aesthetics are not bound to formal artistic creation, but an essential function of sensorial engagement [4]. To which degree, novel systems have been capable of capturing and mediating the emotional experiences that present themselves in everyday life [41].

We identify a motivation and methodology for using wearable sensors as an expressive resource for speechless dialogue, putting aesthetics at the forefront of interaction. Initialised from a thorough discussion on state-of-the art technologies and established design principles regarding this topic, then applied to a novel approach alongside a selection of practice works to compliment this. Given the preliminary proposition of non-representation, the intention is not to infer or classify emotion, but rather create new opportunities for rich gestural exchange, unconfined to the verbal domain. Embracing the right to express oneself from the within, taking the heart, lungs, muscles and motor activity as a basis for maintaining expressive speechless dialogue through the act of being present with the self, others and social environment.

1.1 Core Research Questions

1. **Why** should embodied sensor technologies be used to mediate speechless dialogue?

2. **What** mediums are capable of producing emotionally meaningful representations of physiological signals, suitable for social intervention?

3. **How.** Adopting methods from modern Machine Learning and New Media practices, **how** can aesthetics be incorporated into visuals, sound and haptic mechanisms to articulate and express emotional content? And **how** do we encourage user empowerment and penalisation for effective intervention?

1. Why. Given the layers of novelty and interdisciplinary nature of our work, weaving between the domains of data science, psychology, performance and interaction design, we commit to delivering a comprehensive review of relevant research actions presented in the state-of-the-art, and clearly validate our appropriation of such technologies and practices.

2. What. Part of our research is also devoted to evaluating specific technologies that can be used. Starting from the common wearable sensing modalities, reviewing the interactive affordances of each, along with their corresponding feature extraction methods to retrieve emotionally relevant information. We evaluate methods for producing noel representations and the appropriate mediums for transmitting this between users, whether that be through sound, visual or hardware-based interaction, in a way that balances aesthetic and informational qualities.

3. How. By adopting user-centred principles from third-wave HCI research, already demonstrating success in these areas, we aim to push more towards technical transparency, in that the user is really a part of the design process and consequentially, feel a sense of authority over the system. This assumes a level of responsibility towards proactive sense making, by way of parameter adjustment, personal contributions to datasets. and voluntary participation.

1.2 Collaborations and Affiliations

The works presented have been realised through a process of fruitful collaborations between academic, industry and cultural representatives. The following have sustained the research process in providing financial, technical and . The individual contributions that were derived as result of these collaboration will be explicitly noted where applicable throughout the thesis document.

- **AffecTech, Personal Technologies for Affective Health**

  The PhD was partly funded by the Horizon 2020 initiative, AffecTech. AffecTech is a network funded by the European Commission under the Horizon 2020 Marie Skłodowska-Curie Innovative Training Networks incentivised towards developing personal health technologies for affective disorders.

- **PLUX Wireless Biosignals S.A.**

  The majority of the PhD was supported under the employment of PLUX Wireless Biosignals S.A., responsible for supplying the foundation of technical materials used in the research outputs, namely the BITalino R-IoT device, along with sensory peripherals.

- **Moving Digits, Augmented Dance for Engaged Audience**

  A significant portion of the research was achieved in partnership with the Creative Europe initiative, Moving Digits (MODI). The team were responsible of coordinating field research in the context of dance performance over the course of two years. The project received local support from (M-ITI) and (STL), that were responsible for hosting the workshops and research residencies that are detailed in Sections **??**. The group was also responsible for acquiring participants with specialist skill criteria to take part in the studies.

- **KTH Royal Institute of Technology**

  The division of Interaction Design at KTH Royal Institute of Technology were responsible for hosting a personal research secondment that resulted to the research actions contained in Sections **??** and **??**, accompanied by authoring contributions to the thesis publications.

1.3 Thesis Structure

1.3.1 Chapter 1: Introduction

The current section briefly sets out the underlying motivation and raises major research questions that run consistent throughout the thesis research.

1.3.2 Chapter 2: Theoretical and Technical Concepts

Chapter 2 provides a background to the technical and theoretical concepts that form the foundation of thesis. To begin, we divide the proposed title into four constructs: Non-verbal Communication; Physiological Sensors; The Aesthetic Domain; and Neural Networks. This is used to establish the major themes of the research and introduce conceptual bridges therein. From a technical standpoint, we provide a primer on the different physiological signals commonly used in the corresponding literature, noting their relevance and usability when applied in a given experimental context. We also take the opportunity to introduce some common practices used in relevant research fields such as Gesture Analysis, Social Signal Processing and the philosophical underpinning of Somaesthetics.

Advancing from various of topics grounded in computing and psychology research, we start to uncover a firm basis for aesthetic evaluation in context of technological intervention as social-affective mediation

1.3.3 Chapter 3: Literature Review

In Chapter **??**, we comment on some relevant literature covering the following key topics of interest, first looking at established research fields, namely, Affective Computing, Social Signal Processing, Interactive Machine Learning, Somaesthetic Design, and Non-Representational Theory, then to cover the broad domains of biosignals in creative practice, new media and performance, sensor-based communication strategies and recognised methods for emotional representation. After presenting an overview of a diverse range of topics and research outcomes, we articulate pick out relevant component to cultivate overall perspectives, justifying the intersection of these topics and identifying design principles that adopted the research actions as described throughout the chapters that follow.

e divide the research topics into the following areas, namely: the social impact of sharing physiological activity in human-human interactions, the appropriation of biosignals in creative practice and performance contexts, and methods for inferring emotional states from physiological data.

1.3.4 Chapter 4: Technical Preparations

In Chapter 3, we will introduce and examine a set of hardware and software tools that were developed within the duration of the PhD and adopted for the purposes of augmenting collaborative sensor-based interactions. This will include the design of specialised wearable devices for physiological data sensing in the wild, temperaments for latency estimation, and systems for processing and preparing sensor data for various interactive environments. An underlying aim here is to utilise web-based data transmission protocols to be able to deploy interactive systems in a portable and spontaneous fashion, incentives towards studies to take place "in the wild".

1.3.5 Chapter 5: Preliminary Actions

Our Preliminary Actions 4 are initiated with an individualistic exploration of input-output mediums for physiological representation, forming a broad foundation of aesthetic affordances when testing with our own bodies. Transitioning from an introspective experience, we prepare engagements with a selection of specialist user-groups deemed suitable for providing new insights in a series of workshops that are comprised of focus group, data collection, ideation and evaluation stages.

1.3.6 Chapter 6: Major Case Studies

This will be followed by a collection of case studies that were realised using the knowledge organised from the prior research actions. In Chapter 5. We will present a set of experimental systems developed during the PhD, each intended to establish a theoretical framework for designing systems for emotional exchange. Given this experimental methodology, a matured research space should provoke and sustain discussions around the socio-political implications of technological interventions and appropriation in preparation to be deployed in out-of-lab environments, eventually gearing towards pervasive engagement.

1.3.7 Chapter 7: Results and Discussion

Finally, we are able to reflect on a multi-layered research process and consolidate the overall outcomes that are rooted in the essential research appeal of the thesis. These are ultimately formulated as aesthetic considerations when designing for sensation, representation and communication in context of sensory intervention. In Chapter 6 We open up to some the major limitations present in our work, disclosing the additional paths for investigation that remain unfulfilled, closing the thesis with a call for future work in the push towards aesthetic engagement with communication technologies.

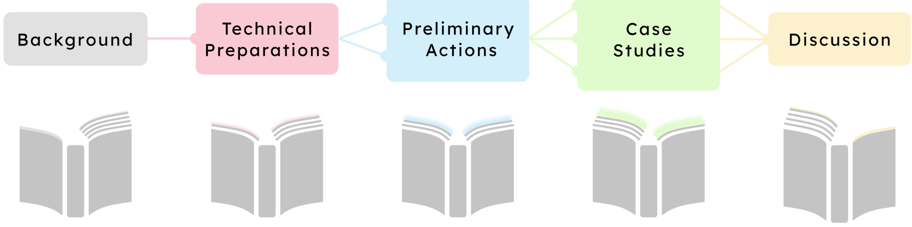

Figure 1.1: Thesis Structure Divided Into Five Stages

2

Theoretical and Technical Concepts

2.1 Non-verbal Communication with Physiological Sensors: The Aesthetic Domain of Biosignals and Neural Networks

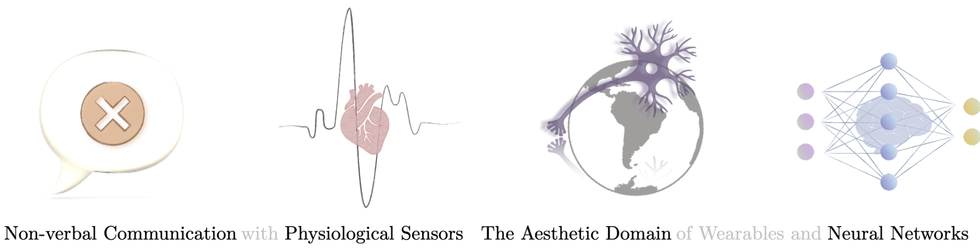

Figure 2.1: Title Constructs Illustrated

We will begin by dividing the thesis title into four constructs that are used to establish the major themes of the research, each accompanied by key references present in the literature. We aim to address some of the commonalities between these that help to unify these concepts into a common research goal.

2.1.1 Non-Verbal Communication

Non-verbal communication is an umbrella term used to distinguish modalities of interpersonal exchange that are independent from speech, many of which are unconsciously transmismitted during social relations, this encompasses a variety of modalities that convey emotions, feelings, and messages. Behavioural analysis grounded in psychology research calls attention to the emotional information disclosed by non-verbal social cues, in particular, actions that are involuntary. Computing and Physiology researcher Alex Petland frames these as *Honest Signals* to articulate a level of emotional authenticity while complimentary studies note the permitted degree of ambiguity.

"The unconscious quality of particular informative non-verbal behavioural cues grants a level of authenticity" A. Pentland and T. Heibeck. *Honest Signals: How They Shape Our World*. English. Cambridge, Mass., Sept. 2010 [36]

2.1.2 Physiological Sensors

Physiological signals provide a measurement of biophysical, biomechanical and bioelectrical changes that occur from within the body. These data streams can be used to validate semantic emotional descriptors based on valence and arousal measurements, linked to the user's involuntary reactions transmitted by the Autonomic Nervous System (ANS). These are widely used to monitor a variety non-verbal social cues, measuring the 'invisible' signals that are otherwise not explicitly perceived.

Non-verbal behaviour is commonly associated with "body-language", aspects such as posture, gaze and other observable traits. But how about bodily signals that are invisible from a third-person perspective? Physiological sensors (or biosignals) are capable of monitoring these internal changes, that can be associated with an emotional response, typically in accordance to a measure of arousal, that operates on a linear scale.

"In other words, nonverbal behavioural cues are the physical, machine detectable evidence of affective phenomena not otherwise accessible to experience, an ideal point for technology and human sciences to meet." A. Vinciarelli and G. Mohammadi. "Towards a technology of nonverbal communication: vocal behavior in social and affective phenomena". In: *Affective computing and interaction: psychological, cognitive and neuroscientific perspectives*. 2011, pp. 133–156 [45]

2.1.3 The Aesthetic Domain

The Aesthetics Domain, to put forward such a heavily loaded concept, we can reduce this to its literal derivative of *aístesis*, which describes the process of perceiving through sensory engagement. Whilst this phenomenon is continually re-evaluated, it can be assumed to operate on a scale of order and complexity. This is essentially how we as humans are able to perceive complex information contained in our surroundings, reducing to a meaningful inference, through a process of learning as a result of personal experiences. From this, we consider ambiguity as an affordance for expressive exchange. In *Two Modernist Approaches to Linking Art and Science*, Eric R. Kandel ties relevance to the art history concept of the beholder's share to the biological understanding of the human mind [26].

"Human emotional life is rich; we can experience a huge number of emotions, possibly a continuum, not just a few for which we have words, like fear, sadness, joy, etc." L. Perlovsky. "Aesthetic emotions, what are their cognitive functions?" In: *Frontiers in Psychology* 5 (2014). DOI: `10.3389/fpsyg.2014.00098` [37]

2.1.4 Neural Networks

An artificial neural network aims to simulate the core functions of the human brain, used to define complex input-output patterns, using previously learned information to comprehend sensory inputs. Combined with the other constructs, we consider the human-like qualities of Artificial Neural Networks as the technical foundation towards emotional engagement with physiological data. As Modern Data Science practices have already validated Neural Networks as an effective method for associating human-understandable contexts to otherwise ambiguous sensor data [6], we reflect upon human-centred augmentations by which the user is immersed in the learning process.

"Treating embodied knowledge as something that cannot be accessed directly and only through examples of action (treating the learning algorithm as a "black box") is therefore missing a lot."

M. Gillies. "Understanding the Role of Interactive Machine Learning in Movement Interaction Design". en. In: *ACM Transactions on Computer-Human Interaction* 26.1 (Feb. 2019), pp. 1–34. DOI: 10.1145/3287307 [19]

2.2 Physiological Signals

2.2.1 Physiological Signal Categories

In this document, we will cover a range of Physiological Signals in the context of potential interaction modalities. Physiological signals can be categorized according to the origin of the activity that is being recorded from the body [13]. The signals we'll be assessing and comparing in this work are defined as bioelectrical and biomechanical. bioelectrical signals provide a measurement of the electric and electromagnetic fields produced by living cells. Examples include Electromyography (EMG), Electrocardiogram (ECG), and Electrodermal activity (EDA) [32]. Biomechanical signals on the other hand measure the physical forces produced by or applied to the cells, tissues and organs. These include respiratory cycles and acceleration of the limbs [20, 35]. The complete list of categories based on anatomical origin is comprised of biomagnetic, biochemical, bioacoustic and biooptical signals.

2.2.2 Controllability of Signals

We take into account the controllability a subject has on a given physiological response, dependant on the source, which can be classified as Voluntary, Indirect or Involuntary. Through Voluntary sources, the user can intentionally manipulate the signal with a high degree of freedom. For example, muscle contractions or join displacements, activities that are associated with the somatic nervous system. Indirect (or Mixed) sources grant the user partial control where as Involuntary sources indicate that there's almost no control over the outcome [42]. Involuntary sources are transmitted from the autonomic nervous system as they occur without conscious control [29].

2.3 Transdisciplinary research culture and Biomedical Engineering

Biomedical engineering is inherently interdisciplinary, it prides self by pulling new perspectives from research fields such as electronics, programming, humanities, culture and psychology, and as such, invite specialists from alternative disciplines to validate insights outside of traditional practices. For affective computing, the study of human psychology is vital for the detection and regulation of emotions using technology. The term lends itself towards a vast selection of applications and research topics, to an extent that is impressive without doubt, but in the expense of obscurity when trying to determine a meaning that is inclusive. For example, biomedical engineering may be rightfully allocated to the production of prosthetic intended for physical rehabilitation [], while on the other hand, it serves as a relevant label for say, a biofeedback system design for guided meditation [17]. What binds these two is the appropriation of biomedical technology and data, which can be divided into two major essential categories: physiological sensors and actuators.

Sensors: These are the components that are responsible for acquiring electrical signals from the body, purposed to measure specific biological, chemical, or physical processes that occur. Section X.X provides a general overview of the common types of sensors modalities as well as their affordances.

Actuators: This describes some form of output mechanism that is being manipulated by the sensor data. The process in which we perceive this representation of physiological activity describes the foundation of biofeedback. In some design contexts, such actuation systems may be referred to as interactive artefacts.

As we begin to appreciate the value of such collaborations outside of the strict by medical domain, we will present our research efforts to continuously defend the inclusion of a aesthetics, primarily in the scope of emotional modelling technology, but also in the broader scope of biomedical science. We foresee a co-benefit between the appropriation of physiologically-centred systems for artistic practices, enhancing our sensory engagement with technology.

2.4 Non-verbal Cues as Social Signals

The field of Social Signal Processing (SSP) can be tied to the increased importance of emotional intelligence in Human-Computer Interaction design [10]. Social Signal Processing revolves around the monitoring of non-verbal behaviour to analyse social interactions. The attention directed towards non-verbal communication can be justified as a method of extracting social signals that's hard-wired in the human brain [44].

A fundamental objective of this work is to explore methods of communicating emotional or affective states without a dependency on spoken language. Non-verbal communication is a term that encompasses a variety of modalities such as posture, physical gestures and facial expressions to convey emotions, feelings, and messages beyond the use of words [27, 39]. This can be interpreted to augment meaning alongside the verbal channel during interaction, or by itself in circumstances where there are only non-verbal channels present.

Non-verbal signals can be described as communicative or informative. A signal is produced consciously in effort to convey a specific meaning is communicative. On the other hand, when the user emits signals unconsciously, without an intended meaning, it is informative [45]. The unconscious quality of particular informative non-verbal behavioural cues grants a level of authenticity, advocating the label of *honest signals* by Alex Pentland [36].

2.4.1 The Embodiment of Emotions

The association between emotions and bodily expression in human and animals was first described by Darwin [11], which has been followed by numerous studies in social psychology, human development (and more recently HCI [1, 18, 16]) to address the communication of emotions from the human body [21]. In this work, we will be working with the existing non-verbal modalities of gesture and posture, which are considered aspects of kinesics. They are both executed from the body and have the capacity to transmit social messages, but can be differentiated by their degree of intentionally and kinematic quality. Gestures are often (though not always) associated with movement and classed as communicative, as they are performed consciously [45]. A subcategory of gestures, known as *adaptors* are performed unconsciously which may indicate changes in arousal or anxiety [22, 34].

Social signals addressed from postures are commonly a result of unconscious behaviour making these amongst the most honest and reliable non-verbal cues according to Richmond and McCroskey [39]. In a seminal work on posture and communication, Scheflen proposes three main social messages to be extracted from an interaction [40], to characterise the posture as inclusive or non-inclusive and to assess the the level of engagement and rapport [46]. Rapport can be associated with postural mimicry (or mirroring), which has been linked to smoother interactions and greater empathic understanding [9].

This notion of the felt experience is compatible with various other philosophical theories proposed in the works of Merleau-Ponty [33], James-Lang [7], Dewey's Aesthetics [12], Lakoff & Johnson [28] to name some, each serving deeply profound insights into perception and emotional life. We won't go into individual details, but appreciate the cohering thread that runs among these is that emotions are not constrained to cognitive function alone, but rather responsive to the holistic body.

2.5 Somaesthetic Design Principles

If we concur with the baseline understanding of aesthetics that was defined in the title constructs (Section 2.1), we can begin to formulate a concise understanding of this phenomenon when we recognise that aesthetic perception is not restricted to our 5 primary sense organs. Shusterman's philosophy expresses the importance of our entire body, and how this is has been used not just to perceive, but how one interacts with their surroundings. Through Shusterman's (Somaesthetic) theory, we can assure that aesthetic experiences are not strictly bounded to a gallery setting or a formal arts education, since the body is inherently capable of cultivating aesthetic value in everyday life. This ability is enhanced through performative practices, such as dance [14]

Somatic practitioners are known to intentionally disrupt habitual actions in order to bring out a third-person perspective, that is to comprehend their experiences from the outside-in, as demonstrated in the "Collaborative Walking' exercise presented as part of the *Move to Be Moved Workshop* [24], that was inspired by Loke and Robertson's method [30]. This process leads us to understand the pinnacle function of technological intervention in contemporary Soma Design theory.

Our approach is informed by the soma design process of Höök [23], which "requires training your ability to aesthetically appreciate all your senses, but also to imagine through your senses, movements and material encounters" [25]. According to a soma design process, what takes form "is not only the digital and physical materials you use to build your interactive artifact with, but also the end-users' somas".

In the wider scope of body-centric HCI research, we include Somaesthetic design as an individual component amongst literature from other research communities, broadly speaking, studies of Moving Computing [MOCO], Tanglable Interfaces [TEI] and Social Robotics, to nominate some key examples. Soma and Somaesthetic design researchers have sustained a profound voice in pushing Affective Computing away it's traditional frameworks of emotion detection, but instead considering emotional experiences enriched by computer mediated interaction (see Section **??**, The Interactional Approach). A plethora of articles and case-studies can be found in the bibliography, with records dating back as far as 200X that demonstrate and assert the relevance of this methodology.

3

Technical Contributions

4

Preliminary Actions

5

Major Case Studies

6

Results, Discussion and Conclusion

6.1 Study Reflections

6.1.1 Interactional Proxemics

As is the case with all kinds of non-verbal behaviours, multi-user proxemic interaction is a complex and an inherently ambiguous process. Without constraining the expressive freedoms that would be granted I everyday settings, a real-time biofeedback system should reflect on this. Though, how do we produce meaningful representations when the raw sensor data is desperately limited in dimensionality and temporal scale? Even more so than data from inertial motion sensors or indeed motion capture.

We already point out the research scarcity for interactional proxemics, continuously outweighed by studies that are favour the use of asynchronous data analysis, not interfering with the interaction space itself. This is pretty much customary throughout Behavioural Computing research, though we may raise the question of why the divide is so intensely divided in this case. Does this simply denote a novel design space that is lacking structural support from academia, or could the experimental reluctance be a consequence of technical challenges specific to the sensing technology?

6.1.2 Combining Sensor Data from Multiple Users

The essence of proxemics implies the use of multimodal information. Our system does not take an explicit measure of orientation, however, we can combine the relative proxemic data from all the sensors in order to distinguish when two or more users are facing towards one another, and register this as periods of mutual gaze. This pluralist gesture reveals a lot about the situation. Generally, we may discern moments of intentional exchange and affirmation, whether that in a comforting or confrontational manner. Of course, this data does not reveal the entire social context by any means, but in contrast to one user staring at the back of the back of another, given the same radial distance, implies a totally different dynamic.

In our system, the sonic representations are designed to emphasise periods of inter-personal gaze. This is detected when the pulse signal from two or more sensors start interfering with one another.

6.2 The Case for Integrating Sensors Data into Movement Practices

Contemporary Interaction Design (IxD) research groups have incorporated Contact Improvisation routines into their work, enlightening new perceptions of mobility through a collaborative practice that involves the transfer of body weight between partners [5, 2]. Where the principal activity presumes that intimate space is to be co-occupied and that touch is freely permitted, in some cases using intense pressure, such practices emphasise the importance of consent and appropriating of physical contact, though several practitioners have come forward to challenge this idealism [43, 3].

In the our initial pursuit towards integrating established somatic practices to the domain of sensory technologies, a two month research residency commenced with KTH, Royal Institute of Technology.The proposed outcome for this collaboration was ultimately to develop an Interactive Machine learning framework that models specific physiological characteristics informed by Contact e. This involved a small series of Contact Improvisation session, guided by an expert practitioner, serving as a somatic connoisseur. Between each activity, would highlight some of the aesthetically informed sensations that occurred, and try to develop sensor-actuation couplings that would mirror the inter-user movement qualities.

On a personal account, the intermediate CI workshops did not enlighten the prolific research opportunities that were naively anticipated up until the research residency. First off, we were not so clear as to the major role of technological intervention. For example, to guide movement patterns in substitute of a facilitator, or exaggerate tactile sensation that occur. In terms of inclusion, the experiential gap between the facilitator and the researchers felt disruptive to personal exploration. Even given a successful digitisation with embodied sensors, how would this experience be distributed outside of the lab or even studio? Without dwelling much further, this segment concludes with the a call to new research directions that realised throughout our research outputs. Ultimately, we are interested in systems capable to instigate interaction without the necessity of explicit instructions. To essentially allow participant to experience the interactive artefact through experimentation, preferably shared with others.

6.3 Limitations

6.3.1 Self Studies and Non-lab Experimentation Settings

The deliverables of the thesis carry upon theoretical underpinnings grounded in complex movement and bodily practices, namely Yoga and contemporary dance performance. It should be noted that the self-studies carried out during the prototyping in the evaluation stages lack the expert opinions of movement specialists, which would require inclusion professional practitioners. While study subjects were able to admit to holding some valuable experience, at least in complimentary practices, we openly the acknowledge having a limited understanding of the rich intricacies that lie in such specialist areas.

In the case of the research actions that called upon specialist uses (e.g Workshops 1.x, CSL Artistic Residency), our results can be praised for interdisciplinary inclusion, for which we benefited from gaining alternative perspectives of the given technologies. That said, this approach without a doubt compromises on longitudinal prospects, imposed by time and budget contingencies. In our case, we found that it was more difficult to obtain structured quantities data from these user studies, as we embraced more an exploration process of the potential affordances, proceeding to outcomes in the form of interviews, focus groups, etc...

We found many difficulties to come against the scientific rigour seen in clinical trials, and the possibility to validate numerical findings. In reflection of the thesis outcomes, we construct a multi-stage research methodology that first embraces the incorporation of specialist users during an intensive preparation period, supporting longer-term studies that can be safely situated "in-the-wild" when ready.

In public space, participants are not being observed, their behaviour, even if not aligned with the study protocol, is authentic. They are responsible for using a system according to their personal intuition, not necessarily what the designer intended. Unlike lab trials, public space experimentation lends itself to unforeseeable events. Every encounter is unique in a way that cannot be perfectly repeated.

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Appendix 2 Lorem Ipsum

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Annex 1 Lorem Ipsum