

Computational Somatics

thoughts on holistic computing

In an expanding system, such as a growing organism... freedom to change the pattern of performance is one of the intrinsic properties of the organization itself.

— C. Judson Herrick

At times also I have been put to confusion and driven to despair of ever explaining something for which I could not account but which my senses told me to be true.

— Galileo Galilei¹

Introduction

There is a deep and dynamic relationship between the evolutionary pathways of computers and humans, each influencing and helping to configure the other². Yet while machines are getting lighter, faster, easier to use, performing ever better at ever lower costs. The same cannot be said of the human, which has not kept up with the raging pace of development of the machine. Humans have not changed in any significant way in the last 200,000 years. There is, however, an illusion of productivity, which reinforces this relationship. Parallels can be drawn between this situation and the psychology of addiction. A damaging habit persists while the illusion of a perceived benefit is fed.

Where critical media theory focuses on the impact that different technologies have upon human culture. The concerns addressed in this writing are slightly different. The impact I am most concerned with is not cultural but somatic, it pertains to the body.

In the same way that when a human misuses a machine the machine eventually breaks down. When a machine misuses the human, it is the human that breaks down. A random google search reveals that the cost of musculoskeletal disorders related to the workplace is around 50 billion dollars a year³. It is clear that work makes humans break down, much work today is done together with a machine. Humans are breaking

¹ «*Discorsi e dimostrazioni matematiche, intorno à due nuove scienze*», Galileo Galilei, 163

² «Flesh and Metal: Reconfiguring the Mindbody in Virtual Environments», N. Katherine Hayles, [link accessed 28/1/2013](#)

³ National Research Council and the Institute of Medicine (2001). Musculoskeletal disorders and the workplace: low back and upper extremities. Washington, DC: National Academy Press. Available from: <http://www.nap.edu/openbook.php?isbn=0309072840>

down and machines are suffering the loss of their users at a staggering rate.

Humans continue to neglect some fundamental aspects in their integration with the machine, the effects this has on their psycho-physical condition are disastrous.

It is a well established fact that machines affect the ways humans think. Friedrich Nietzsche suffered from disease, at some point he could not sit to write for extended periods. As a way to get back to his writing, Nietzsche adopted Malling-Hansen's Writing Ball (Skrivekugle) a precursor of the modern day typewriter.

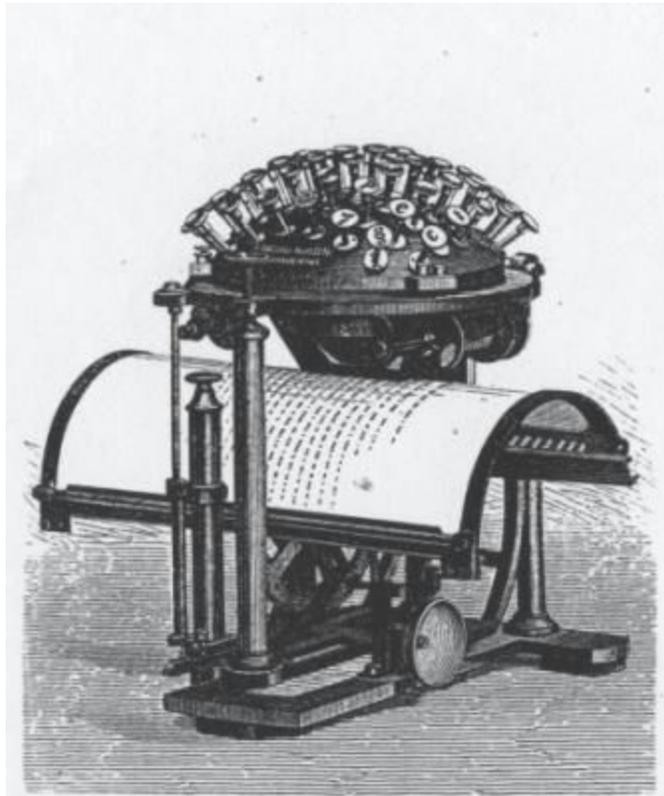


fig 1. - Skrivekugle, 1878, Rasmus Malling-Hansen ([image source](#))

One of Nietzsche's friends, a composer, noticed a change in the style of his writing. His already terse prose had become even tighter, more telegraphic. "Perhaps you will through this instrument even take to a new idiom," the friend wrote in a letter, noting that, in his own work, his "thoughts in music and language often depend on the quality of pen and paper."

"You are right," Nietzsche replied, "our writing equipment takes part in the forming of our thoughts." Under the sway of the machine, writes the German media scholar Friedrich A. Kittler⁴, Nietzsche's prose "changed from arguments to aphorisms, from

⁴ *Gramophone, Film, Typewriter*, 1999, Friedrich Kittler, [link accessed 4/11/2012](#) (pp. 201-8). An article covering the

thoughts to puns, from rhetoric to telegram style. Malling-Hansen's writing ball, with its operating difficulties, made Nietzsche into a laconic"⁵.

Investigating the relationship

CATCHPA questionnaire

www.spinningkid.info/nanosites/hci/

Please guess what is the relationship between the two elements shown in the picture above.

What's the human's profession?
e.g. nurse

What's the computer doing?
e.g. searching patient records

Now please prove that you are human...

This

Type the two words:

reCAPTCHA™ stop spam, read books

I solemnly submit »

fig.2 - Online questionnaire. ([access it here](#))

To investigate common perceptions in the relationship between the human and the machine, I created a simple online questionnaire. The image above was displayed alongside two questions “What is the human’s profession?” and “What is the computer doing?”. I published this test on social networks and got members of my faculty as well as friends and acquaintances to participate. To ensure that all responses were produced by a human subject, I placed a CAPTCHA⁶ test that had to be fulfilled before submitting any response.

subject in wider scope is available at ROSA B a webzine co-produced by the CAPC musée et l'École des beaux-arts de Bordeaux, [link accessed 2/2/2013](#).

⁵ *The Shallows*, 2003, Nicholas Carr.

⁶ A **CAPTCHA** is a type of challenge-response test used in computing as an attempt to ensure that the response is generated by a human being.

The only clear pattern that emerged was the idea that the nature of the relationship between the human and machine was one of subjugation. A very few people perceived the machine as being the subjugate, most respondents in this category perceived the human as being the one subject to the machine.

These participants have very likely developed a sensitivity that allows them to observe this relationship at a distance and reflect on its meaning. This group is important as they constitute the revolutionary core.

the machine

Nihil est in intellectu quod non sit prius in sensu⁷

Nothing is in the intellect that is not first in the senses

In her essay *The Death of the Sensuous Chemist*, Lissa Roberts tells a riveting story of a crucial period in the history of science that has Antoine Lavoissier as one of its protagonists. Prior to this time, chemists used their senses to analyze the matters they worked with. It was not uncommon for a chemist to taste urine and analyze its properties from what was plainly available to the senses. The training of a chemist involved years of developing a literacy of nature through the senses, gas concentrations would, for example, be determined by factors such as smell or temperature. This education was a lengthy process in which the apprentice had to be sensitized to the point that they could use their bodies to detect all the subtle discernments necessary to pursue chemistry with success.

Lavoissier was essential in formalizing the new science of chemistry by promoting an innovative synthesis of principles that were introduced by a network of fellows in the eighteenth century, including laboratory equipment, experimental techniques, pedagogical approaches and language to discuss findings.

Analysts in the new chemistry had to master new experimental techniques that required them to subordinate and discipline their own bodies in the service of the material technologies of their laboratories.⁸

This is not to say that chemists stopped altogether smelling, tasting, touching or listening in the course of their work. But knowledge gained in this way came to be regarded as unreliable, arrived at by intuition and more importantly, as non-discursive given the requisite for precise measurements demanded by the new language of the new chemistry. The machine began to be seen as the primary means to attain trustworthy scientific knowledge and technology became the means by which knowledge could transcend the body.

⁷ *De veritate*, Thomas de Aquino, q. 2 a. 3 arg. 19 ([source accessed 27 May 2013](#))

⁸ Essay *The Death of The Sensuous Chemist* in the book *Studies in History and Philosophy of Science*, p. 506

The Cartesian Machine

The most decidedly modern of machines is the digital computer, but the computer is a particular kind of machine in that it is not designed to extend human limbs, make them stronger or protect human from predator. Like the abacus and other technologies before it, the computer is a machine designed to extend the power of human reason.

The use of reason as the principal means of attaining knowledge, is a major pillar of western philosophy. As Jonathan Israel argues "after 1650, everything, no matter how fundamental or deeply rooted, was questioned in the light of philosophic reason"⁹. The philosophical milieu of the time was perhaps best summarized by Descartes transcending statement "Je pense, donc je suis" ("I think, therefore I am"). It is only through intellectual reasoning that human can know human. The breach between mind and body in western philosophy widened substantially during this period.

What more evidence of extreme cartesianism in the current technological worldview does one need than the dualism existing between software and hardware? The digital computer, this most ubiquitous of technologies is a manifest case of the way technology has developed under the Cartesian worldview.

The computer can be said to be the most Cartesian of machines, for the human capacity that it codifies is logical inference itself and its distance to embodied operation the greatest yet that has existed in any other technology before it.

Mechanical Turk as the last job standing

It has been one of the most elusive promises of science that in twenty years¹⁰ computers will be as smart as humans. This particular kind of techno-utopia continues to be promoted by the aging rearguard of the Artificial Intelligence (AI) community¹¹.

⁹ Israel, J. (2001), *Radical Enlightenment; Philosophy and the Making of Modernity 1650–1750*, Oxford, Oxford University Press, p. 3

¹⁰ At almost every milestone of AI covered by the press there's a scientist supporting this promise that always seems to lay 20 years from now. This was the case in 1997 when Deep Blue beat Kasparov at chess. In 2011 when IBM's computer Watson competed in television show "Jeopardy!". The promise of AGI (Artificial General Intelligences), meaning non-specialized intelligent behaviour, has been proposed by intellectuals as Michio Kaku, Ray Kurzweil, Ray Korowai, Hans Moravec, John McCarthy, the list is much longer than this space affords. The idea of AGI seems to have captured the imagination of scientists, inventors, sci-fi writers and the general public alike, the fact that the promise has not yet materialized seems to disappoint none of them. ([related link](#))

¹¹ One example of a member of this community that is very much in line with this idea is inventor Ray Kurzweil, in his book *How To Create a Mind* as he continues to expound a variation of the Computational Theory of Consciousness as recently as 2012. This theory states in very rough terms that consciousness can be atomized into processes, individual computational tasks that together add up to generate cognitive output.

In the utopian landscapes proposed by this promise, humans are freed of mundane repetitive labour, work is performed by ever more intelligent machines and humans have plenty of free time to enjoy the wealth generated by the work of machines.

The currently existing relationship between human and machine is far from the promise of AI. The machine now pervades every aspect of the human's working life and far from making space for more free time the machine is now portable enough and offering sufficient connectivity to make work possible anywhere anytime. Humans take this feature as an opportunity and work at all times with careless abandon. The shift in labour is not only quantitative but qualitative as well. Machines perform tasks at the convenience of humans and humans do what machines can not yet do. As machines become more capable in a general sense, humans become more specialized to fill the gap of the machine.

One example in which the machine's capability has surpassed that of the human is cancer diagnosis. It turns out computers are more accurate in the diagnosis of breast cancer than trained humans are¹². It would therefore be irresponsible to not adopt machines for cancer diagnosis as it would mean that a greater number of human lives would be saved by introducing more accurate diagnosis of early signs. This also means that it would be, not only less than optimal but also irresponsible to continue giving this job to a human¹³.

As the machine further erodes the territories that were reigned by humans in yesteryears . It becomes inefficient, inviable and at times even immoral for humans to remain doing certain types of work. Machines however are not yet capable of carrying out all necessary work by themselves.

The use of human intelligence to perform tasks that computers are currently unable to do is becoming a niche market. Humans performing such tasks are called Mechanical Turks¹⁴. Global online retail giant Amazon offers HITs (Human Intelligence Tasks) for humans to perform in exchange of money, at the time of this writing, some of the tasks listed include: rating the credibility of a piece of content, discerning dialects from streams of arabic text, writing an engaging callout, describe the color of a product, rate images for adult-only content, proofreading a publication. At any given time there are around 3000 HITs listed on the Amazon marketplace. Some of these HITs are in fact perfectly doable with a computer today and soon most of them will.

¹² *Systematic Analysis of Breast Cancer Morphology Uncovers Stromal Features Associated with Survival*, 2009. See link to Science for full list of authors. ([link](#))

¹³ For a broader discussion on the moral of the machine you may refer to Appendix A.

¹⁴ The name Mechanical Turk comes from *The Turk* a chess playing automaton made by Wolfgang von Kempelen. It was later revealed that the machine was not an automaton at all, but was in fact a chess master hidden within the guts of the machine controlling moves against the opponent. ([source](#))

It might seem a far fetched idea that the last jobs where human labour will be required will be those assisting machines, but the current trend is to incentivize this kind of human-machine relationship in labour and there are no signs of this trend reversing.

The codification of civilization

In one of his lectures, Daniel Dennett showed a slide containing an old instruction manual for elevator operators, from back in the day in which operating an elevator was a job carried out by a human. It contained clear and concise instructions such as "emergency exits at either side of the car must be closed when in motion". Dennett spoke of how these manuals have been progressively codified into technologies as either electronic devices or software. In the process of codification a great deal is lost. Certain directives are dropped, some new ones created, ambiguity and moral judgement are replaced with feedback loops.

car is full and signal transfer switch is
thrown.
(7) Passengers should not be hurried.
It is both dangerous and discourteous.
(8) Operators never give information

fig. 3 - Example of a directive for human operators that cannot yet be codified into a machine.

In the words of Simon Penny “any tool, soft or hard, is a mechanistic approximation of a narrow and codified aspect of human behavior. [...] Tasks which are simple and open to variation for a person, must be specified and constrained when embodied in a machine”¹⁵.

Concealment of the rules

In the process of codification certain aspects of the codified task are lost. The process of trying to find the rules encoded in a system by looking at nothing other than the system itself is called Reverse Engineering. At first encounter with a codified system most humans find severe hurdles in their understanding of it. Few things about its internal workings are revealed to the untrained eye. Details of a system's inner workings are elusive even to expert eyes. Some systems enclose so many encoded abstractions that at times it is impossible to fully grasp how they all play together as a whole. This is one of the reasons why codification affects comprehension. The machine cannot easily transmit knowledge about the abstractions that it codifies.

Systems can sometimes reach such levels of complexity that indeed no single human can even begin to understand how they work. In the Flash Crash of May the 6th of

¹⁵ *Body Knowledge and the Engineering Worldview*, 1996, Simon Penny. ([source](#))

2010, the Dow Jones index plunged about 9% in the course of a morning, 600 points alone in just 5 minutes at exactly 2:45. The causes for this were unknown at the time but had to do with High Speed Trading. High Speed Traders are algorithms executed by very fast computers that operate on real-time market data, sometimes buying and selling within nanoseconds. These tiny transactions scratch only fractions of pennies on every transaction. But because these operations are performed in really huge numbers every day, can amount to millions and millions of dollars worth of trade. The technological arms race that these trading conditions have created is as interesting as is ludicrous. Each of these algorithms in operation get triggered on certain conditions, so for example when a particular set of shares that are interrelated present an oscillation in value, a particular algorithm might be triggered to perform a sale. Whereas another algorithm operating in the same arena, under the same conditions might trigger a *buy* action. Making this market a vast pool of codified rule sets that affect one another and where no single entity has an overview of how the whole works.

The new ecosystem of the machine is an Economist's wet dream. All these trading agents, performing their actions rationally, with equal access to information, with human emotions ruled out of the market. A perfectly rational system, the very essence of the science of Economics.

Yet what happened in the Flash Crash was unexpected and might never be fully explained. It is now known that a glitch in price reporting might have triggered the downward spiral that was then exacerbated by High Frequency Traders, but the complexity of the system and the opacity of the rules codified in each individual trader make an accurate assessment of the causality positively impossible.

No single human being has a detailed understanding of how these systems work.

Disembodiment

A lot of *apps* available today replace a technology that previously existed as a physical device. Making the smartphone the ultimate generic tool that can perform the tasks of hundreds of other devices that previously required to be manipulated by a human in the physical world.

What before was pushing keys in a calculator is now tapping the touchscreen of a smartphone. What before was manipulating a water level, is now balancing a smartphone's inclination sensor.

As devices and the software running on them become more capable, software simulation quickly becomes the dominant aspect of the machine. The more generic the hardware, the more specific the software seems to become.

All codified aspects of an activity buried in the machine exist in a realm of ideas away from human consciousness, accessible only to the expert. The machine becomes a black box. With the process disembodied, the human using the machine that makes the thing, hardly ever learns to make the thing itself. As Simon Penny put it “the process which links conceptualization to physical realization is destroyed”¹⁶.

As the machine specializes it is the human that becomes stereotyped, the human becomes a “standard part”, an interchangeable element in the chain, a parameterized formula in the design of machines. The more ergonomic the design, the more stereotyped the human.

Extraordinary development of the machine

F.M. Alexander found a causal relationship between technological development in the build-up toward the first World War and the “crisis of consciousness” that ultimately led to war¹⁷.

[...] "The extraordinary development of machinery, which demanded for its successful pursuance that the individual should be subjected to the most harmful systems of automatic training. The standardized parts of the machine made demands that tended to stereotype the human machine" [...] "The power to continue work under such conditions depended upon a process of deterioration in the individual as he is slowly being robbed of the possibility of development"

This thought of Alexander is what nourished the idea of what John Dewey called the Degeneration of Civilised Unconscious. It is important to note that Dewey was not talking about this process as a cultural trend, but rather as a tragic disconnect between means and ends. Being subject to change but never in control of the process of change itself, or at any rate aware of it at all. Change happening below the buoyancy level of collective consciousness.

Alexander understood that awareness of this process of change and the development of awareness to exert some level of control on it, was a process that had to occur through the body and one that must be experienced before it is understood.

¹⁶ *Body Knowledge and the Engineering Worldview*, 1996, Simon Penny, paraf. Simulation and the Demise of Body Knowledge ([source](#))

¹⁷ *Man's Supreme Inheritance*, 1910, F. M. Alexander. p. 102 (Commercial Industry and Militarism)

the human

You say “I” and you are proud of this little word. But greater than your word is your body which does not say “I” but performs “I”.

— Friedrich Nietzsche

Lack of a discursive framework

Telling a person to sit up straight for example, is not enough to convey all the information necessary to achieve that goal. There is an interpretive stage in all verbal commands dealing with the body mediated by proprioceptive sensation. For example, what is straight for one person might be arched too far back for another. Words often fail to convey all the information necessary for a bodily movement to occur. Even demonstration sometimes fails, as most dance teachers will attest. Showing how to make a move doesn't mean that all students will be able to reproduce it exactly. Kinesthetic information is very hard to convey to others. Humans lack an unequivocal channel to communicate this kind of information. Some people need to reason the movement and understanding it first, others need to see it to understand it, yet others will not grasp it until they have mastered it in their own bodies. Kinesthetic information does not travel easily between humans by means of words alone.

Many of the studies on kinesthetic sensation I have come across during my research, have their origin in discussions pertaining to its function and dysfunction. Scientific knowledge of the body's kinesthetic sense is spread out in disciplines as disparate as medicine, air force pilot training and sports coaching. However a substantial percentage of this knowledge has palliative or preventive goals. That is to say, it originates from the will to alleviate the symptoms of disease or the effects of dysfunction. There is very little literature focusing on the experiential aspects of kinesthetic sensation per se in a way that is not merely functional and descriptive.

There is a significant lack of vocabulary to develop a critical discussion of kinesthetic sensation.

Thinking in motion

An exception to this finding is the remarkable case of F.M. Alexander. The discoverer of a universal principle of motor control and the inventor of what is known as the Alexander Technique. Mr. Alexander was a rare case of kinesthetic genius, a person that developed a very high sensitivity for human kinesthetic sensation and developed an intelligent understanding of the effects it plays in the whole organism. He had to develop a specific vocabulary to communicate his findings as he seems to also have encountered a lack of language to discuss kinesthetic sensation. This vocabulary is nowadays common parlance amongst practitioners of the technique, but it is not widely disseminated. Terms such as *faulty sensory appreciation* or *debauched kinesthesia* are unfortunately not in wide use.

The truth remains that humans hardly ever feel the need to discuss kinesthetic sensation until they feel that something is the matter with their bodies.

Debauched Kinesthesia

It is said that a person's kinesthetic sense is *debauched* when the misuse of their body is such that they are no longer capable of telling which energy state their body is in. Whether they are using too much effort to hold themselves or too little, or if they are compensating for some kind of imbalance existing in their use. Their kinesthetic sense is therefore unreliable as it is no longer providing accurate feedback to the brain.

It is interesting to note that this is "learned". Humans are born with a naturally balancing body, it is through education, or perhaps better said, lack of education, that the kinesthetic sense comes to be debauched.

The nature of kinesthetic sensation is to exist in the background, hardly ever surfacing into consciousness. To remain below conscious levels the human motor system has an ingrained capability to compensate for undue effects by changing the tension patterns across the entire body. For example, waking up with a stiff neck the body tries to cope with it. Undue tension appears on the shoulders and lower back, trying to compensate for a stiff neck, head position changes slightly with respect to our torso. The variation in the shoulders means our arms become slightly rotated inwards and greater tension in the lower back means our legs bear a greater burden. Humans hardly feel any of this, and even long after the stiff neck has worn off through the day the tensional pattern that compensated for it echoes through the body. For most humans all of this happens way below the line of consciousness.

Smell artist Sissel Tolaas once said that humans breathe about 1200 times per day, every time inhaling scented molecules. Smell is there at all times, there are smells to be perceived at every moment of life. Yet humans are hardly ever conscious of this. She tells how, for seven years, she trained herself as a *supernose*, a person capable of distinguishing a great variety of smells even when present at very small concentrations¹⁸. In the process, she describes, how her attention gradually shifted and was more and more taken by a world that seemed to be rich in smell wherever she went. Entering a room became an experience rich in aromas of all kinds, layering in different ways. It was no longer possible for her to ignore, she had become conscious of this sensual dimension. Her smell, no longer operating under the threshold of consciousness.

Kinesthetic sensation, in this sense, is not that different from smell, except that normally it is buried even deeper from our consciousness than smell is. It is possible to learn how to more accurately perceive kinesthetic sensation by bringing this sensation into consciousness.

Kinesthetic information

Every time a human jumps to fetch a frisbee, there is a huge amount of activity going on in the body. The calculation of the trajectory, which might be influenced by wind or many other factors. Planning the motion and tensional patterns required for the body to reach out for the catch, as well as coordinating and timing these movements accurately. This happens so fast that by the time the body is halfway through that motion, the conscious mind is already looking ahead at where to throw the frisbee next. The entire body collaborates in this feat of engineering and makes it appear effortless. From skin and hearing, humans get information about wind strength and direction. From joints, vestibular sensation and vision they obtain the relative position of body and limbs to the desired position, from ligaments and muscles they receive information about effort and strain. Vision, hearing and touch provide information about the direct physical environment as well as the brain's mapping capabilities tell the human if there is a tree where she has to move next.

No system engineered by humans manages to resolve problems like this with quite such grace as organic bodies do. Examples of these phenomenal feats of engineering abound in the natural world and it's not the purpose of this section to discuss them at any length. What is important to understand however, is that all these motions took place, for the most part, without surfacing to the conscious level. To consciously calculate all factors involved in catching a frisbee in an analytic and conscious way, would quickly overwhelm most humans. Yet a healthy person, in full command of their motor system can do this without thinking.

¹⁸ Personal notes of lecture by Sissel Tolaas at the Goethe Institut Amsterdam, 16th January 2013.

Most kinesthetic information that the body feeds the brain with, lives in a tumult of activity way below the buoyancy level of consciousness.

F.M. Alexander didn't just develop a rational understanding of kinesthetic sensation and a vocabulary to discuss it critically, he also developed a way to convey information through his teachings. However kinesthetic experience cannot be taught by means of words alone. He found that to convey kinesthetic information he had to use his hands to transmit more precise directions.

The anomaly of sitting still

The human body exists in a state of finely tuned dynamic balance. Its Upright Posture involves two distinct features: first, the rising up against gravity, which requires intense muscular effort; and then the substitution of this effort for a most delicate poise and balance, an equation of forces brought about by an interplay of the sensory and motor mechanisms. The Upright Posture, once attained is reliable and effortless as well as highly unstable.¹⁹ It is probably safe to assume that no human has ever lived that has never experienced a fall.

It is to the Upright Position that humans owe the liberation of their arms and hands, allowing for the development of fine manual dexterity, which arguably is one of the evolutionary drivers towards a larger brain.

The center of gravity of a human being is comparatively at the highest point amongst mammals, making the Upright Posture very unstable. Quadrupeds and other bipedal mammals have much lower balancing points than humans. Observing quadrupeds standing on their hind legs, like horses rearing or dogs begging, it is clear that they do so with great effort and never for too long a time. A high center of gravity gives the human body a greater store of potential energy, making a large range of movements possible with very little energetic expense.

Bipedal locomotion is in a way a fluid mechanism to prevent falling. To walk forward, a human leans forward slightly, bringing their center of gravity forward, effectively provoking a fall, which is then compensated by bringing one leg forward to reach again a state of balance. Walking is a flowing motion produced by continuously falling forward. It is a curious fact that even to walk backwards a human being must still lean slightly forward.

From a mechanical point of view it is clear that the dynamic balance of the Upright Posture is an advantage for continuous movement. The human body is much less

¹⁹ *Balance as a Function of Intelligence*, 1970, W. H. M. Carrington

satisfactorily adapted to keeping still.

A human body in stagnating stillness wants to collapse and fall, give into gravity, to avoid this it must find the support of something else, a wall, a chair perhaps, even the floor. Balance in the Upright Posture exists only while there is motion.

hci: the human as appendage

Virtual Realities - Real Concussions

When I was about 12 years old I went to a trade fair near my town. Years later the only memory I keep is the following anecdote.

While walking around with my grandfather I saw that the local bank had a very flashy and futuristic booth where you could experience a virtual reality environment. In it there was a text that said "VIRTUAL (n) that which is real, but doesn't exist". There were three people wearing head mounted displays and looking around in slightly encroached body poses, as if they were amongst a swirling flock of birds attacking them. I had seen these VR systems in science magazines and I knew about the lore surrounding them, but I had never before experienced one.

I waited in line for what seemed an eternity and finally I got to the VR station. Every set had a stewardess assisting the public, my stewardess for this experience handed over the HMD and gave me a few explanations, I couldn't really listen to her, I was too overexcited by the presence of the Silicon Graphics stations, glistening under the theatrical effect of the spotlights.

After the stewardess reset the trip, the HMD showed what seemed like a church, with stained glass high up on some walls and very ample spaces. I couldn't really see my arms or any part of my body as I had seen in movies. The graphics were slow, I could see the frames changing and the viewpoint catching up to the position of my head after a considerable delay. I moved my head around fast, trying to explore the whole virtual space in the little time I had for living this experience. I was not aware of what was going on outside of the HMD, the outside world was entirely locked out for me.

As I moved my head around I had no perception of the location of the stewardess. While I queued I had seen her before helping people to not get caught up in the cables that connected the HMD, but I had no idea where she was with respect of me, or even which way I was looking at in the real world. At some point she must have got pretty close to me because I felt a dry and strong bang, followed by a muffled shriek. Next thing I remember was my grandfather talking to me from my back, saying that I had to come out that I had been there for too long and had hurt the stewardess. I was very confused.

When I took my HMD off the young woman was sitting on a chair, just behind the

computer setup being assisted by a colleague. My grandfather approached her to apologize in my stead. Her hand claspng her forehead. Apparently I banged her head pretty badly with one of the hard-edges of the HMD. I can't say that I was very worried about her, the excitement of the experience and the intensity of my disappointment about such crude technology, was stronger than my compassion for the stewardess at the time.

I remember the whole experience as intensely disappointing.

In retrospect and with the knowledge I have gained since, that incident has contributed considerably to shaping the way I understand the discipline of HCI (Human-Computer Interaction). With the advent of every new human-computer interaction technology there's always a human having to make an adaptive leap and a trail of people with some kind of physical side-effect that results from maladaptation. Every new development in HCI is marketed as "easier to use", "more natural". From the mouse to the Kinect, every controller has claimed to revolutionize the way we interact with the machine and every single one of them has left a trail of injured humans along the way.

New, newer, newest

Humans seem to be quite ready to adopt new forms of interaction irrespective of the ignorance on the impact these technologies have on the perception they have of their own bodies.

Wireless networking for example is a technology that has quickly spread to every corner of the planet and it was not until it was widely spread that studies were conducted to understand the impact it has on the human. This is in fact an ongoing experiment.

This general attitude of the human on the face of new technologies, opens a realm of almost infinite possibility for the machine. The field of HCI parasitizes this special status that humans concede to technology. Humans seem to have no trouble to subject the body to untested technologies for the sake of novelty.

Psycho-physical modalities

“One of the things I always liked about the Moviola is that you stand up to work, holding the Moviola in a kind of embrace [...] Editing is a kind of surgery -- and have you ever seen a surgeon sitting to perform an operation? Editing is also like cooking -- and no one sits down at the stove to cook. But most of all, editing is a kind of dance -- the finished film is a kind of crystallized dance -- and when have you ever seen a dancer sitting down to dance?”²⁰



A particular form of dysfunction comes from forms of interaction that lock the human body into a single modality of use for extended periods of time. Modalities are psychophysical in the sense that both the psychological state and the physical use together conform a modality. A person can be said to be listening or speaking, or constructing and irrespective of their concrete activity we can make assumptions about the state they find themselves in.

A healthy human subject in a wakeful state of full awareness, is multimodal in state and potential. Not only is the subject fully engaged psychologically and physically, but the subject is free to change these states effortlessly in a natural flow from one modality to the next. In this sense there are no interruptions, simply because they do not exist. When something else calls for attention a person in a wakeful state can shift modalities without ever fully abandoning their activity, only the modality and the subject of engagement change but the person never abandons a state of full engagement. This is a natural modality.

Multimodality is a word often used in HCI parlance but I argue that its meaning is perverted in discussing human forms of engagement as it is derived from a machine

²⁰ *In the blink of an eye - a perspective on film editing*, 2001, Walter Murch

centric view. An interface is said to be multimodal when it provides several distinct means for input and output of data. This is a good thing as it supposedly increases the usability of a system. However this apparent beneficial effect only takes into account total data throughput between human and machine and assumes that redundancy and synergy are beneficial to the human. This definition of multimodality relies on how much attention the machine can have from the human.

An example of this is the head-mounted display (HMD), by providing visual and aural feedback as well as tactile means of navigation there is a high data throughput between the human and the machine. But the human loses awareness of the world around it. A person trying to engage somebody else that is wearing a HMD is sure to be interrupting. What one earns in immersion in a multimodal interface one loses in awareness. In this sense even so-called multimodal HCIs are in fact, locking the human into one modality of use, this is why I resist the notion of multimodality in HCI and would rather call these interfaces multi-channel instead. These types of interfaces make full conscious awareness practically impossible. The human becomes absorbed in a single modality of use, the one which is established by the interface.

Technobondage

I call this locking the human into a modality, a relationship of *Technobondage*. This kind of relationship is applicable to the chainsaw as well as to the computer. All technologies bring with them implicit propositions for bondage of the human. The machine is needy and the human forgiving.

Technobondage is a purely intellectual exercise, a kind of fetishism, that relies in the psycho-physical subjugation of the other for a momentary sensation of pleasure derived from a sense of efficiency. It is a mechanised form of Sadism in which the catharsis is eternally delayed.

It is no wonder that humans derive pleasure from the destruction of machines. Catharsis is only possible when the dependency is broken. Only then can consciousness return. At the same time this catharsis is necessary for the death of the machine, evolution can only exist where death discards the obsolete and inadequate. It is by the destruction of technological forebears that new technologies get made.

The least worthy way for a machine to die is to become a museum piece. A mere display item, a historical sample, for it is then that the logic of the technobondage gets turned in its head, as it can no longer subjugate the human.

HCI is obsolete

HCI as a discipline is based on a principle that no longer holds true, that human and machine ought to be distinct. While one performs computations the other performs interactions. This is a dualistic view, consistent with the Cartesian machine and oppressive of the body.

Most efforts in HCI have in one way or another produced gadgets that require the learning of a *somatic grammar*. By *somatic grammar* I mean a set of bodily movements that when combined can convey to the machine the intention of its user. Whether this somatic grammar involves dragging a piece of plastic over a rough mat and clicking on buttons, or calibrate thoughts with a device that picks up brainwaves, is besides the point, in either case there is a grammar of use. This grammar is composed by an ever growing set of somatic verbs, drag, drop, click, swipe, pinch, tap, rotate, shake, bump, think up, think down. None of which are part of a human's natural use, they have to be learned, and the gadgets often need to be trained or calibrated. The phrase: "move to last photograph, select it and zoom in to see a detail" could be translated into the somatic grammar of some smartphones as: "swipe left, swipe left, swipe left, double tap, pinch, swipe". This succession of verbs forms a sentence that expresses an intention to the machine.

There is a reason why they have to be learned, let the latest gadget be an example for why this is so.

At the time of this writing a new gadget called MYO is being advertised that uses electromyography as a gestural interface to a computer. Electromyography is a technique that picks up electrical pulses sent by the motor control nervous system to individual muscles. MYO can understand these signals and translate them into a model of tensional patterns in the arm and fingers, allowing for the recognition of very detailed and very specific gestures. It is in MYO's website, in the FAQ section that one can find a succinct expression of why MYO is more of the same. "We use a unique gesture that is unlikely to occur normally to enable and disable control using the MYO."²¹ It is this "unlikely to occur normally" that pervades all the somatic verbs that enable interaction between human and machine. It is this trying to distinguish a gesture that wants to communicate an intention to the machine, from a gesture that would occur naturally, that directly opposes the possibility of integration.

²¹ MYO product frequently asked questions (Source: <https://getmyo.com/faq> accessed 10 March 2013)

malfunction

"Effective operation is done without awareness. Or we can define awareness as that which happens when we malfunction"²²

- Stelarc

Awareness as a malfunction

Often times people struggle to find the right words to describe where or exactly how something feels in their bodies. Most lack sufficient knowledge of anatomy to point out to their partners that it itches most between the *rhomboideus* and the *latissimus dorsi*. Instead humans find bits of their bodies through manual reconnaissance. They scratch and scratch until the precise point where it itches is found, only then do they find relief.

Lacking the verbal capacity to describe bodily sensation is a limitation but not a vital impediment. The body operates quite effectively while sensation happens below the threshold of awareness. It is only when the body stops functioning normally or when sensorial input contradicts sensation that awareness sharpens and what before was unconscious now surfaces as a concern. It is then that words seem lacking.

It is this feature of body operation that I seek to exploit. In this light, a malfunction could be introduced artificially, that would help the subject bring proprioceptive sensation to the level of conscious awareness.

Hackable Senses

The human sensory system is composed by the terminal points of millions of nerve fibres that interpret and carry information to other parts of our body. This information is the result of concrete stimuli, as each of the nerve cells that compose the sensor reacts only to a particular kind of stimulus. A photoreceptor in the eye for example can only be stimulated by one type of light. Human beings have four types of photoreceptors in their retinas. The aural receptors in our inner ear cannot be stimulated by light, they only transmit information when stimulated by sound. Whatever the actual interpretation the senses might give to stimuli, what is clear

²² Stelarc And Smith, M. 2005. Animating Bodies, Mobilizing Technologies: Stelarc in Conversation. In *Stelarc: The Monograph*, Smith, M., Ed. Cambridge: MITPress, (pp. 215-222)

though is that "each nerve can only respond to stimuli in a specific way; therefore our knowledge of the world reflects the structure of our nervous system"²³.

An approach to tamper human sensation is by providing fabricated stimuli to the nervous system in the specific ways in which it can process them. This way it is possible to fool the sensory system into processing sensations that do not come from real-world phenomena but from a machine simulation. This is exactly how the controlled malfunction that is proposed in this paper works.

The human nervous system receives as input the signals that a computational process produces as output.

My interest in this research is not rooted only in experimenting with human-machine interfaces, but to better understand the cognitive processes of perception. A lot of knowledge exists on visual and aural perception, but during my research I found significantly less information about kinesthetic perception and its role in consciousness. Curiosity naturally lead me to dig deeper into it.

Proprioception

"The inner sense by which the body is aware of itself"

"An Anthropologist on Mars", 1995, Oliver Sacks

The ground below the feet is the most important reference point to the body's sense of space, the contact of the feet propel the body upwards and keep it in dynamic balance. Humans sometimes mistake perceptions of their position relative to the Earth. You might have experienced this when you are sitting in a stationary train and the train next to you starts moving. For a few moments it is hard to tell whether you are moving or standing still. This kind of spatial disorientation occurs when humans receive contradictory information from the variety of senses that contribute to the perception of position in space.

Some humans get nauseous when they read in a bus, their eyes are fixed on the text of the page that moves along with them and so it appears stationary to the eye, yet the vestibular system is perceiving the motion of the bus and of the body with respect to the Earth. Many people get dizzy as a consequence, although sensitivity to these sensations vary among different people.

A dancer explained to me that when she goes into an old wooden house, where the floor and stairs are uneven and at varying angles, she gets a very unpleasant sensation

²³ *Academy of the Senses*, 2012, Frans Evers

in her stomach followed by a strong desire to leave the place. She can feel the disorientation caused by conflicting sensorial sensations and her expectations.

The body's perception of itself is mediated by the proprioceptive sense. This sense uses input from different parts of the body to determine its own position and posture. Skeletal joints, ligaments, muscles as well as the vestibular system in the inner ear, hearing itself and vision intervene in the body's understanding of its own position in space. The system formed by these inputs is redundant, this means that two of these systems can be providing information about the same sensation. When one of these systems provides information that conflicts with information provided by another there's a momentary cognitive dissonance. This dissonance manifests itself by raising awareness, what was happening below the line of awareness before, becomes a conscious cognitive process.

In an anechoic chamber, for example, is impossible for the body to determine how close or far it is from a wall, these kinds of chambers have specially designed walls and floors where sound becomes trapped and cannot bounce back. So the human ear cannot appreciate the room's acoustics.

In microgravity it is impossible for the body to tell which way is up. An external reference point that can be identified visually is needed.

By providing artificial input to the vestibular system it is possible to induce in a human a sensation of spatial disorientation. There are several approaches by which this could be achieved, but I will focus on the one that is specific to my work.

The Vestibular System

This complex system consists of three semicircular conduits located in the inner ear, each providing sensations for its orientation and motion with respect to one axis in three-dimensional space. So for example the movement one would use to say "no", rotating the head sideways, would provide stronger stimulation through one of the conduits, the one that sits in the horizontal with respect to the floor; the stimulus would be less strong in the other two conduits. The actual science is rather more complex than this explanation would indicate but my point is that this organ detects forces by sensing *differentials* in the sensations provided by these conduits.

The three conduits converge on two receptacles inside the inner ear called the *saccule* and the *utricle*. Inside of each of these, there is an organelle called the *macula*, which acts as a sensor and can measure forces through nerve terminations that are attached to hair-like structures that are suspended in a semi-liquid membrane.

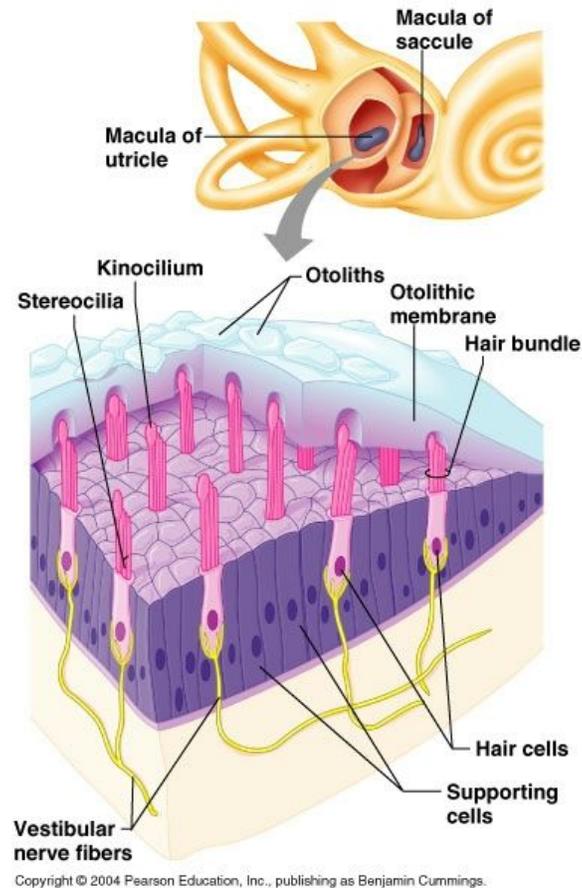


fig. 4 - Structure of the maculas in the inner ear

These small differences in sensing one axis of movement over the other, give the vestibular system a measurement of the forces that the body is subject to, which in combination with other senses give us a pretty accurate understanding of how our body is moving in space.

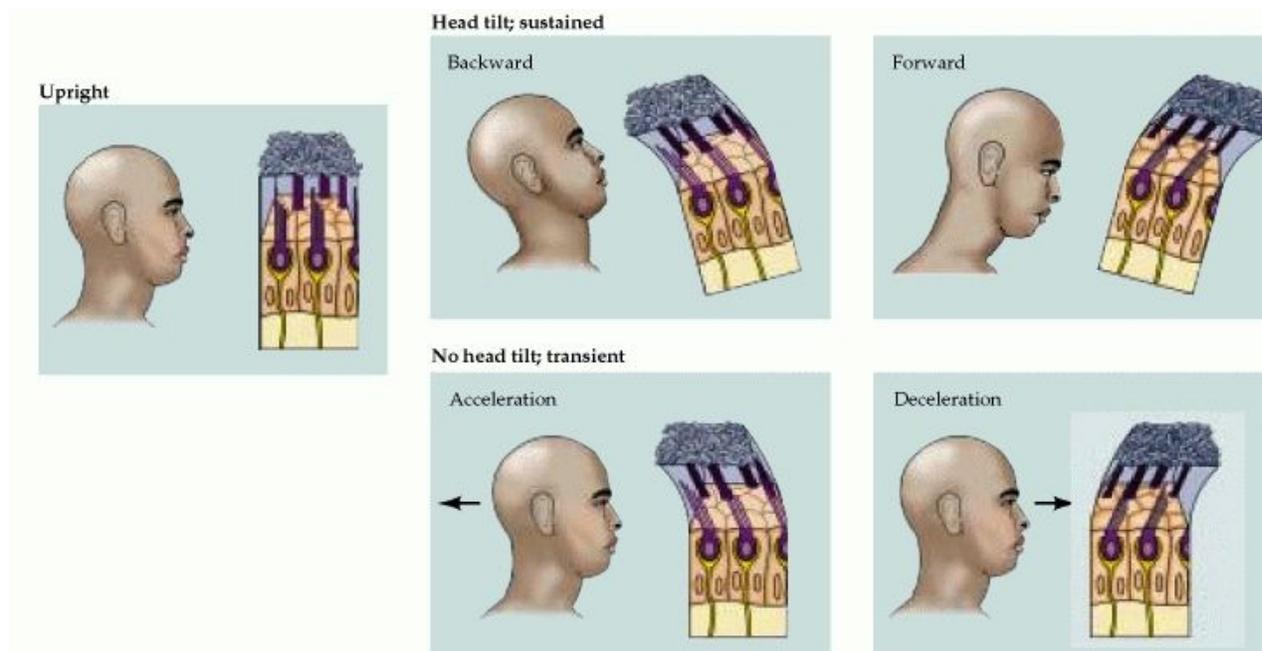


fig. 4 - Schematic of how head movement affects the maculae.

The vestibular system is also principally responsible for balance. Abnormalities in vestibular sensation can have a severe impact on a person's balance and capability to orient itself during bodily motion to the point of serious impairment. People suffering from *Ménière's Disease* know this all too well. First described by physician Prosper Ménière, vertigo can be caused by inner ear disorders such as infections.

These sensations can also be induced artificially through several techniques such as injecting hot water into the ear followed by cold water, Epley's maneuver which is a therapeutic exercise or a special type of electrical stimulation named GVS which is the one that concerns this research.

What is GVS?

The technique more broadly known as GVS was discovered in the eighteenth century when Alessandro Volta reported feeling dizziness after he applied current through his head. Volta, inventor of the battery, put electrodes attached to a 30 Volt source and applied them to his ears, resulting in what was described as "an explosion inside of his head, including loud noises and disorientation"²⁴.

Since 1820, when Johan Purkyne described the technique in his dissertation, GVS has been used as a technique to study the function of the vestibular system.

²⁴ Fitzpatrick, Richard C., and Brian L. Day. "Probing the Human Vestibular System with Galvanic Stimulation", *Journal of Applied Physiology* 96 (2004): 2301-2316. Medline. Cal Poly State University, 17 May 2008

GVS stands for *Galvanic Vestibular Stimulation* and it consists of the transcutaneous stimulation of the vestibular apparatus. The vestibular system is situated in the inner ears, both left and right, and is responsible for providing the brain with information about orientation and inertia. The brain then uses this information in combination with visual and aural input to determine the position of the body in space.

Artificial stimulation is achieved by placing electrodes on the skin covering the mastoid processes (fig 5) of the temporal bone. You can feel these protrusions if you touch a human skull just behind the ears. Creating an electrical field between these areas on both sides of the skull produces a very coarse stimulation of the vestibular system. The mastoids are just below the brain, so current doesn't go directly across the brain.

The nerve terminations in the *maculas* are sensitive to changes in this electrical field and the vestibular system tries to compensate with a response in the sensation of balance that makes the subject lean towards the anode (usually marked +).

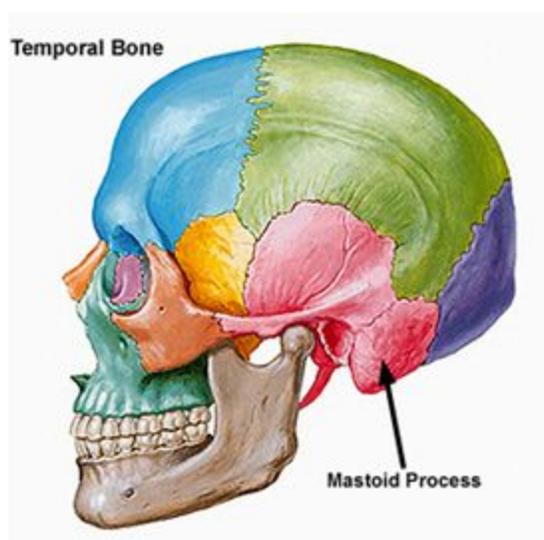


fig. 5 - location of mastoids

Early experiments

The circuitry required to induce GVS is in fact very simple, all one needs is a way to regulate the current (amperage) so that it stays within non-painful thresholds (below 5mA) and place the regulating circuit between the source and the electrodes.

Once I had a primitive circuit that could produce vestibular stimuli I connected it to a

microcontroller and wrote a piece of software that could play back a fixed sequence of stimuli. I experimented on myself for quite a while, performing different activities such as walking along a line, drawing two parallel lines on the floor, standing on one foot with eyes closed, tip-toeing along a path, executing repetitions of balancing exercises such as drunk tests, tai-chi forms, running, spinning, balancing on a fence, standing upside-down on my hands, standing on a gym exercise ball and many more. I tried many of these activities to understand the effects of the stimulation on my own perception of balance. I recorded some of these exercises to try and see if these effects could be visible by an external observer.

My findings after these experiments proved that the experience was rather consistent. GVS is strongest with eyes closed but most confusing with eyes open. Repetitive tasks make the effect more obvious to an external observer. The effects are very subtle, it is hard to tell when someone is under the influence of GVS unless there is some comparative framework. All activities become much more challenging when under the influence of stimulation. For example, drawing two parallel lines on the floor about 10 meters long, took about 1' 30" without stimulation and almost 3' with stimulation. Both trials resulted in properly drawn parallels, but analysis of the video showed more postural jiggling, more resting pauses and more general postural discomfort on the trial with stimulation than on the one without.

In the following two illustrations Fig 6 and Fig 7, a point on the head was tracked in a video capture of the author executing a simple activity, drawing two parallel lines on the floor. The blue track shows the path of the head without GVS, the red path shows the path of the head under the influence of GVS.



fig 6. drawing two parallel lines on the floor without vestibular stimulation



fig 7. drawing two parallel lines on the floor under the influence of vestibular stimulation

The effects of GVS

A subject walking in a straight line will deviate their path when subjected to GVS and will lean slightly towards the anode in an effort to compensate. I would describe the sensation as being in a boat and feeling that the floor beneath the feet has tilted slightly. The deviation is subtle but externally visible to an outside observer, the subject appears to be out of control of their motor capability, very much as if the subject was drunk and incapable of walking in a straight line.

A human can function normally under the effects of GVS but to do so must use considerably more effort as every move becomes challenging to execute with precision.

When stimuli follow each other too quickly or alternate directions, the sensation will induce a mild nausea in most subjects.

The sensation caused by GVS isn't pleasant as it is somewhat disorienting. When levels of current are limited to reasonable thresholds (3.5mA), the sensation is not painful but still unpleasant.

One of the pioneering researchers in GVS as an interactive interface, Taro Maeda, has published several papers that infuse with great enthusiasm fantastical applications to this form of stimulation. My personal experience with it has led me to think that one shouldn't expect popular uptake of this kind of technology any time soon, as it is unreliable, requires careful calibration and when functioning correctly it still results in a feeling that is quite unpleasant.

Getting used to it

I have been subjecting myself to GVS for a little over a year and a half now and I have developed an interesting somatic response to the sensation that repeats consistently. As I subject myself to GVS I feel the tensional patterns in my body compensating for the sensation, this results in a subtle stiffening of my posture starting on the neck in an attempt to feel steady. My body has learned a new habit from electric stimulation.

Over the course of my research my sense of balance has developed greatly and I can now detect subtle changes in the tensional patterns of my body. I cannot give full credit to the GVS for this improvement, as my research involved learning other techniques that have these changes as their stated goal such as the Alexander Technique. But GVS has been instrumental in testing my progress and has been decisive in bringing the sensation of balance into conscious thought so that I could analyze my own movement through proprioceptive feeling.

My research led me to a deeper understanding of proprioceptive sensation and a method to manipulate it with some consistency, but until this point I had been preoccupied mostly with reproducing existing knowledge. As a visual artist it was frustrating to me that proprioceptive sensation was so difficult to communicate and share with others. Indeed as dance theorist Barbara Montero once wrote on its aesthetic potential:

"Proprioception poses a unique problem: aesthetic senses seem to require a distinction between the object one senses and the bodily sensation itself, a distinction that can be made with sight, smell, taste, touch and hearing. However, proprioception, it might be claimed, cannot focus our attention beyond ourselves"

"Proprioception as an Aesthetic Sense", Barbara Montero

To increase awareness of proprioceptive sensations, I try to induce a malfunction. This malfunction is regulated by a computer controller and the effect I seek to have is to inhibit and direct movement. I use GVS as a technique to produce dissonance between what is felt and what is seen.

But could this feeling be shared in any way? Could someone "proprioceive someone else's movement" as Barbara Montero puts it?

The BRAID system

BRAID is an autonomous wearable system composed of two devices designed to extend the sense of proprioception of two actors. Each device registers the wearer's position and broadcasts it to all the nodes in the mesh network on the stage. As a response, the other device produces small electrical pulses that stimulate the vestibular system of the wearer, altering their perception of balance. When one of the actors leans very heavily towards the left, for example, the other will feel a proportional stimulation towards the opposite side.

This system was designed by speculating what a shared feeling of proprioception could feel like and building a new medium for proprioceptive sensation from existing techniques.

The system is composed of custom-developed electronics for transcutaneous

stimulation and the computing platform is based on off-the-shelf parts like Arduino and XBee wireless networking modules.

The devices

The BRAID devices are encased in a box with a posterior lid shaped as a belt buckle that can be easily mounted on a strap. Each of these devices can keep track of head movements through an accelerometer²⁵ mounted in a headband and connected to the device through a flexible five lead ribbon cable. The two additional leads are outputs from the stimulation circuit that are connected to two medical electrodes that the wearer applies on the skin that covers the mastoid processes. The connectors (in red in the picture) are hand made as they went through many redesigns during the prototyping phase.

The intensity of stimulation can be manually regulated through a potentiometer on top of the device. This is an essential part of the design as the device requires frequent recalibration by the wearer, as skin resistance varies through the duration of a session.



²⁵ An accelerometer is a type of electronic sensor that can measure acceleration with respect to the force of gravity. This means that an accelerometer at a resting position on the floor will measure the force of gravity 9.81 m/s^2 . The BRAID system uses 3DOF accelerometers that measure accelerations in a three dimensional axis.

Fig. 8 - Two devices of the BRAID system, with one mounted on a wig stand.

These devices run on a 9V battery that serves as power source for all the components inside as well as the transcutaneous stimulation. They run for about 2 hours on a single charge.

Postural Zero

In the first five seconds after the device is turned on it tries to figure out the center balancing point by averaging thousands of measurements of the wearer's position in a calibration loop. So if the person is in a normal standing position, the device will understand *that* position as the *Postural Zero*. Or if the person is laying on their back, *that* will be the *Postural Zero* and therefore standing up will result in a deviation from the *Postural Zero*.

Large deviations from this *Zero Position* will result in stimulation in the other devices in the network. This feature of the system allows actors to change their *Postural Zero* during a performance, or try different starting positions during rehearsals.

Inputs and outputs

The system gathers data about the dancer's position with respect to their *Postural Zero* and uses those deviations in two different ways depending on its mode of operation which can be configured through a switch in the front of the device.

Each device has two kinds of outputs, status and stimulation values. The status values comprise information such as battery charge, mode of operation, current and voltage readings and the stimulation value is a single signed value that indicates polarity and strength of stimulation.

All inputs and outputs can be processed by a monitoring node in the network to produce visualizations or sonifications of the data. This is useful for live performance as each of the parameters transmitted can be mapped to a visual or sonic feature in the scenography.

Modes of operation

Each device has two modes of operation, *manual* in which the input gathered by a single device is not broadcast and is used by the device itself to determine the stimulation that its own wearer will receive. So the wearer can stimulate itself, this mode is often used for testing or exercising.

The other mode of operation is *auto*. In this mode input data from the accelerometer is broadcast to other nodes and each node processes all data except the self generated. This is the mode that permits that the inclination of one actor will result in the stimulation of another.

Networking

Each device is fitted with an XBee module configured in mesh mode. This means that each device can communicate with every other device within range. The current system supports two devices only due to budgetary constraints, but each device contains a unique identifier and the system can scale to many more devices.

The status of the network is refreshed at a frequency of 28Hz, a slightly slower rate than the rate of operation of the device and this does not include latencies derived from poor signal or low battery levels. The range is about 20 metres with line of sight to about 6 meters without. They work quite well on a stage environment. When the system is operating in a mesh node it doesn't have the capability to connect to IP networks, but adding a monitoring node (e.g. a computer with an XBee explorer module) could relay all traffic in the mesh network to an IP network.

My personal computer serves as the monitoring node in the current system, but it is not needed for normal operation on the stage.

Levels of stimulation

The device can provide levels of stimulation that can vary from 0 to 3.5mA with 0 to 24V of potential. The maximum cut-off current is 3.5mA which was advised as a reasonable level to remain medically safe, the stimulation circuit never exceed this limit. This limit can be pushed down if it's too strong for the subject. The device contains an internal potentiometer that can bring down the current limiting factor.

when the system is engaged in activity the dynamic level of stimulation is computed as a factor of the inclination received from another device. Through the following factor

$$P_{stim} = P_{max} (I_{input} / I_{ref})^3$$

Where P_{stim} is the value of stimulation, P_{max} is the maximum stimulation that the system is capable of, I_{input} is the value of inclination received from the other node and I_{ref} is the normalized mean inclination. The cubic formula insures that very small variations in inclination will zero out, while significant variations in inclination will result in more pronounced stimulation. This formula was determined experimentally through trial

and error, until the level of stimulation “felt right”.

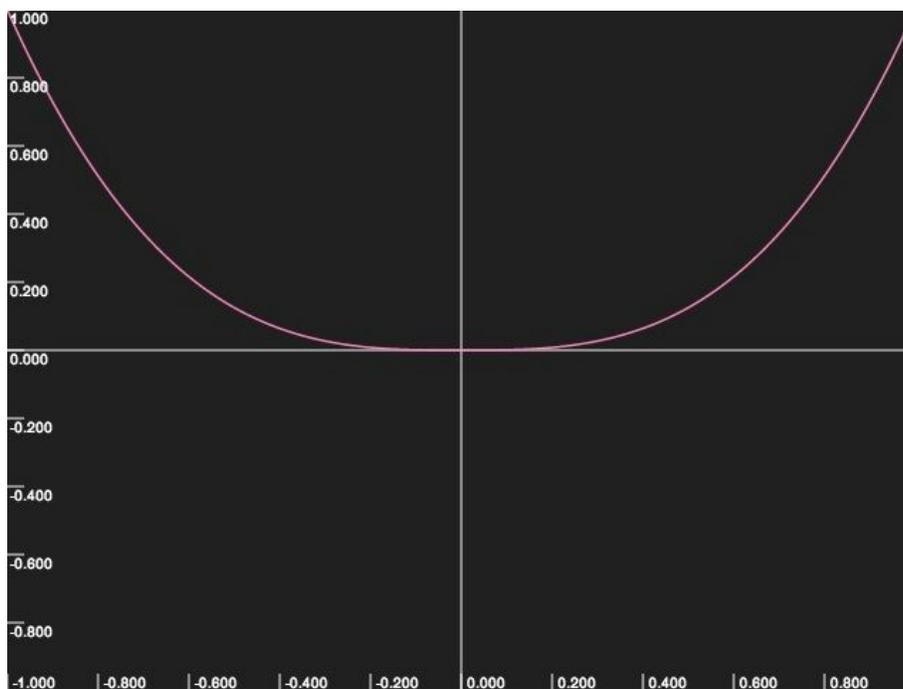


fig. 9 - correlation between inclination (horizontal) and level of stimulation (vertical)

This formula means that the receiving actor doesn't feel anything much at all until the one inflicting hasn't moved about 50% away from their *Postural Zero*.

The level of stimulation is determined by a microcontroller by using a pulse width modulation (PWM) signal running at 31.25kHz. The microcontroller uses easing algorithms to smooth the signal in and out. This is necessary because sudden changes in electric stimulation through the skin often have nefarious effects on it, causing decomposition, irritation and even pain if the changes are too sudden. Smoothing the stimulation signal can avoid some of these problems.

Record and Playback

The BRAID system has the capability to record sessions, logging all positional data of all the actors and is capable of playing it back in the form of vestibular stimulation on another subject. This opens the possibility, for example, to share proprioceptive sensation through a recording of an event in the past. Or across geographical areas through IP networks where the actors can be much further apart than they could on the stage.

Dealing with the skin

How to best transmit the electric pulse through the efficiently and without pain is a challenge in all forms of electric stimulation. The BRAID system uses standard medical electrodes used for TENS (transcutaneous electric nerve stimulation) devices that are popular with passive exercising machines and electrophysiotherapy. I settled for these electrodes because they allowed me to progress faster with my research than I was while making the electrodes by hand. The electrodes are round and have a diameter of 3.5cm and come with very steady 2mm wide nozzles for external connection.

The size and shape of the electrode has a role in the electric field that they create around the inner ear, so the electrodes are in fact the most essential element in successful GVS.

The mastoid processes are a rather difficult area of the body to apply electrodes, they are round, they are often covered by hair and the ear is too close while it must be avoided as it is more sensitive to electricity and has a lower pain threshold than other parts of the skin.

After wearing the electrodes on the stage for a session they often become less sticky and end up peeling off. We opted for surgical tape to keep them in place on the stage but this will have to be researched further in future versions of the system.

Future work

During the design and making of this system I have learned a great deal about the body and its interaction with electronics. The devices are rather bulky in their current design and there are microcontroller platforms today that have a much smaller footprints and offer a wider range of features. I estimate that the size of the device can be brought down to the footprint of a wristwatch with existing technologies and with a small redesign of the stimulation module.

The recording and playback feature has a great deal of artistic potential allowing for installations or geographically dislocated proprioceptive experiences and I would like to explore these possibilities in future works.

Conclusion

Throughout this paper I have laid bare the reasons why the relationship between humans and machines is in need of reformulation. Continuing to design machines that utilize humans as intelligent appendages, is not a viable option for the continued development of either machine or human. We have seen the ways in which performance of one is intimately tied to performance of the other. In the same way that mono-modal machines contribute to what John Dewey called a degeneration of the human unconscious. Human's excessive bend towards the Cartesian divide produces machine designs which are inadequate for a natural multimodal flow.

We have seen how HCI is a fundamentally flawed endeavour as it insists on viewing this relationship between the human and the machine from a single point of view inevitably generating impoverished ideas.

It is important at this point to distinguish biofeedback-based art from *Computational Somatics*, while the first focuses on signals from the body captured by a machine, the second doesn't make such distinction. The other direction is also possible within *Computational Somatics*. That is, that a computational process be somatised in a human body.

The work of Taro Maeda in the research of GVS as an interactive interface was infused with an infectious enthusiasm about the possibilities of this technique. I was quickly taken by it and started my own research progressively becoming aware of its limitations and discovering new potentials. The idea of sharing vestibular sensation is hinted at in Maeda's research but it is mentioned as a potential application. BRAID is the first materialization of this possibility that I am aware of.

There has been few attempts at using GVS in an artwork, but it seems the technique has become a curiosity rather than something worth exploring in depth for its expressive potential. The possibilities that Maeda laid on his papers have not yet materialized and remain in the realm of the speculative but the potential he unveiled is still untapped.

In my own experiments I realized that the fundamentally unpleasant effect of GVS, will continue to keep this technique within a reduced circle of adopters, perhaps in research and the arts and I do not foresee (at least not at the moment) an uptake of this

technique among the general public for interactive experiences.

I have persisted in the pursuit of GVS despite disappointing first results, because I saw it as a means to make possible a medium for proprioceptive sensation and the BRAID system is designed with this purpose in mind. As a platform for experimentation in performance, for actors to share something that until this point has been an intimate and personal experience, one's own sensation of balance.

the morality of the machine

In a previous chapter there was mention of the moral dilemmas that certain technologies bring in their wake. For example, knowing that the machine is the best means available for the early diagnosis of breast cancer, it would be irresponsible indeed arguably immoral to not deploy these means where they can be afforded. This side of the moral equation belongs to the human and every major technology has brought with it comparable conundrums. Take these token technologies as examples of the human side of the moral equation: the nuclear bomb, genetically modified organisms, nuclear waste disposal. In these cases the objects themselves do not have a moral dimension.

Digital computers are a different kind of technology however, because they introduce a very primitive kind of moral agency. By being exceptionally good at executing statistical models, computers become agents that make decisions on the face of uncertainty. Machine morality is not determined by moral values, but by numeric values. It is bounded by the laws of statistical modelling and the possible coordinates of a decision exist within the bounds of the following matrix, commonly known as Confusion Matrix.

True Positive (TP) correctly identified	True Negative (TN) correctly rejected
False Positive (FP) incorrectly identified	False Negative (FN) incorrectly rejected

Confusion matrix²⁶

Numerous cities across Europe implement some kind of computer-based statistical model designed to identify number plates in cars. At the time of this writing the False Positive (FP) rate of these systems ranges between 8% to 15%. This means that about that many people get fines that shouldn't be getting them. One could argue that the decision to deploy a system with this failure rate is ultimately human. At some point it was decided that the cost to deploy such a system would be less than the benefits of deploying it, and so the failure rate is assumed as a mere statistical fluke, to be

²⁶ Concepts extracted from *Some Useful Statistics Definitions*, 2005, Lee Newberg

compensated for by human labour in filing and processing claims that dispute machine-made decisions.

One could argue that the moral decision belongs to the system designer or the programmer, because in the face of uncertainty a *default* decision is given as output. When the maker fails to honour the principle of *Occam's Razor*, that states that among competing hypotheses, the one that makes the fewest assumptions should be selected. A *default* decision is a fabricated assumption and so the designer would be in direct violation of *Occam's Razor*. A lax moral standard in the maker gives rise to an incipient morality of the machine.

Machine morality can then be defined as the capacity of the machine to make the wrong decision when instead it could make no decision at all.

In the first kind of moral dilemmas, the kind in which a technology has no moral dimension in itself. Bruno Latour suggests that "to become moral and human once again, it seems we must always tear ourselves away from instrumentality, reaffirm the sovereignty of ends, rediscover Being; in short, we must bind back the hound of technology to its cage."²⁷

Such rosy escape route is not afforded when moral decisions themselves are encoded and executed by digital computers, when the machine is both the means and its very existence an end in itself. The hound that bites human is human itself.

²⁷ Latour, Bruno, and Couze Venn. "Morality and Technology The End of the Means." *Theory, Culture & Society* 19.5-6 (2002): 247-260.

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Acknowledgements

To Marijn van Dongen of TU Delft, which was kind enough to receive me in the early stages of my research to share his experiences on galvanic vestibular stimulation (GVS) as well as offering feedback on the design of a device that would be safer to use.

To Antahl Ruhl who was kind enough to also share his knowledge, including the design of his own device as well as offering advice on the conditions of skin for optimal stimulation.

To Kike Max for introducing me to the Alexander Technique and for the very many discussions that we had on balance and the human body. For his gentle approach to teaching and his inspiring generosity. As well as Laura Clemente, Andreas and Ainhoa, ATCA graduates as well as students for spreading the teachings of F. M. Alexander and tending to my questions with generous attention.

To Cocky Eeck and Arthur Elsenaar for offering their experience, support and useful feedback along the way.

To Rene Wassenburg for the shared enthusiasm about stimulation technology and for the wonderful engineering he made based on my impractical specs.

To Olga Balague Ponz and Victoria Luna for their support.

Many thanks as well to the people that have contributed with insightful conversations, comments and kindness including Didac Verdaguer, Kerstin Heyen, Sue Bamford, Inda Peral Ortega, Arantxa Rosado, Isabel Alonso Pola, Cecilia Dino, Martine Neddham, A. Shaw, Femke Egas, Cecilia Dreytmuller, Eelco Wagenaar, Esther Verhamme, Sara Palomeque, Diana Wildschut, Harmen G. Zijp, Lilia Perez, Teresa van Twuijver, Marco Donnarumma.

Also to my fellow master students: Daniel Berio, Jonathan Reus, Momoko Noguchi, Virginie Dubois, Panagiotis Tomaras, Mischa Dams, Nenad Popov, Sarvenaz Mostofey and Izolda Griner.

As well as the ArtScience faculty and the coordination assistant Leonie Zweekhorst.

To the venues of our preview show Grote Markt, HOOP, Korzo Theatre and Vrije Academie.