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The biological encoding of design: the premises for a new generation of “living” products.
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05. Abstract

The following article aims to briefly describe the long and intricate search path which led to the design of Sinapsi, a smart device inspired by nature, for helping blind people’s mobility and orientation in track and field. The description will be accompanied by an analysis of different solutions already developed for helping blind people and by multiple thoughts, theoretical and methodological, that aim to critically explain the renewed role of design, as well as to highlight the importance of biological reference in a complex world populated by artificial intelligence.

In particular, we will show how inspiration from biological systems can be one of the most innovative and attainable methods, not just to incorporate biological characteristics into machines and artifacts (nothing particularly new, even in AI) but to use it in the design process of smart systems as an instrument for improving quality of life and to expand our best human qualities. In fact, the growing complexity derived from the AI systems' increasing degrees of autonomy has raised issues concerning the relationship between the user and the intelligent entity, as well as important ethical issues that call into question the design and that can be overcome through inspiration from the logic and the principles governing the intimate intelligence of nature.
Finally, the explanation becomes particularly interesting and deep when we talk about assistive devices for sensory disabled people, in which the co-dependent relationship between the user and the technology becomes stronger and in which the boundary between help and substitution, between enhancement and helplessness, risks fading.

06. Article

1. A complex scenario: our technological "Next Nature".
Artificial Intelligence is the branch of computer science, the offshoot of cybernetics, that aims, as science, to study certain smart behaviors (such as the interaction with the external environment, learning, reasoning, planning) and, as engineering, to reproduce them in the man-made world, to give materials, products, and technologically advanced systems the ability to think (Amigoni, Schiaffonati, and Somalvico 2008). It is not by chance that the trend defined as "A.I.fication" will develop from our era of Industry 4.0. Smart cities, process automation, smart objects, dynamic systems, robots, and everything we can define as "technology-driven" will lead to a world populated by complex technological artifacts (tangible and intangible), able to perform real behaviors, rather than performances.
Therefore, we can easily deduce that it is among the leading disciplines responsible for the process of the "biologicization" of the "realm of the made" (what is artificially built) with which we, as humans, have surrounded ourselves since the most ancient origins; but that today is rapidly evolving towards such complexity, as to show characteristics more and more similar to those found in the "realm of the born" (what is naturally generated), increasingly integrating with it according to the same "operating law" (Kelly 1994). In other words, like in a reverse process, sophisticated technological innovations bring us back to nature: life mechanisms cease to be merely theoretical models and became real production processes which, increasingly applied in a transversal way to almost all the sectors of human activity, lead to the concretization of anthropic entities that we can, for the first time, define as "living."

In fact, the so-called AI “intelligent agents” are comparable to living organisms existing in nature, which by definition, are able, at the genotypic level, to contain and manipulate information and, at the phenotypic level, to assume real complex behaviors and information processes suitable to survive in a given environment, by relating their genetic tools with the conditions and the perturbations from the outside (Schrödinger 1995).
However, while this has allowed today’s technology to produce dynamic, adaptable, sensitive, and multifunctional entities which can alter their physical properties, including information, senses, and responding to the environment’s demands (Kapsali 2016), adapting to the needs of the contemporary “liquid” society (Bauman 2012), it has allowed our system of tools, machines, and ideas to become so dense and interrelated as to achieve a kind of independence, to begin to exercise a certain autonomy (Kelly 2011). Intelligent systems such as the Internet, financial systems, or genetic algorithms show how our technological environment – traditionally created to protect us from the forces of nature – is becoming so complex and uncontrollable that it is giving rise to a “Next Nature” which is just as cruel, unpredictable, and threatening as ever and in which the boundary is fading between technologies that facilitate our humanity and ones that rob us of our human potential (Van Mensvoort 2012).
In this new scenario, several social and ethical issues are raised, especially concerning the relationship between humans and technology and it becomes particularly interesting and profound when we talk about assistive technologies for sensory disabled people, technologies that aim to make the lives of these individuals easier and higher quality. In fact, in this case, the co-dependent relationship between the user and the technology becomes stronger and, as such, the boundary between help and substitution, between enhancement and helplessness, risks fading away. Pondering these questions led to the studies and the experiments that gave rise to Sinapsi, a smart device inspired by nature, for helping blind people’s mobility and orientation in track and field. In particular, questions arise as to how these new intelligent technologies can be useful to blind people, what types of constructive relationships there can be between them and the user, and how the design culture can find, in this field, but also in general, suitable and sustainable solutions in a world in which the artificial dimension is becoming a new nature, complex and out of control.

2. The role of design.

The idea that the relationship between humans and technology (from the Ancient Greek "tékhne-logìa" [1] - broadly meaning anything useful produced by our minds and willpower) is something as natural as our life is by no means new, nor is the belief that technology will determine our evolutionary future and allow us to be more human than even before. In fact, as revealed by the Greek suffix -logìa (conversation, reasoning), technology, unlike the simple tékhne- [2], implies a relationship between “doing” and the more general socio-cultural background, thus entailing a unique vision of the world that influences and changes us: not only the way we live and act, but also our way of being and thinking (Massaro and Grotti 2000). However, if it is true that from the earliest origins humans have surrounded themselves with “structural” artifacts to extend their bodies and “superstructural” artifacts to extend their minds, through which they managed to survive through a co-evolutionary symbiotic relationship with technology, then it is also true that the process of hominization risks ceasing when the loss of control over technology opens the possibility of transforming this relationship into a parasitic one which, unlike the symbiotic relationship, lacks reciprocity. As Koert Van Mensvoort (2012) said, since the dawn of our existence, human beings have been co-evolving with the technology they produce, in the same way bees and flowers have evolved to be interdependent, but every co-evolutionary relationship runs the risk of becoming parasitic, in which the stronger exploits the weaker. This is the risk we now face in the era of “A.I.fication”, in which technology is becoming more and more intimate and in which multiple thinking entities are crawling autonomously around us, colonizing our body, manipulating our behaviors, settling rapidly between us and everything around, collecting mountains of information about us, and even simulating human behavior (Van Est et al. 2014).

Therefore, in mankind’s race for adaptation and survival, for overcoming weaknesses and reaching self-perfection and efficiency in all human activities, man should cherish the thing that is perhaps our most precious possession: attention. Man must live consciously in this world, monitoring the activity of the multiple thinking entities that surround him and using them as a means to improve the future of mankind rather than as a replacement, keeping his social and emotional skills alive, being alert to his right to make free choices, managing the way information reaches him, and developing himself. In fact, in applying today’s sophisticated technological advancements, a tension between the control that technology exercises on the individual or on society and its potential must always emerge, even beyond the uses defined by its developers: is not the technology itself that determines its uses, but the ideological and cultural position generating them (Langella 2007).

From this perspective, design – both as a discipline that arises in the context of an artifact project, in which social issues and lifestyles are translated into anthropic entities and as a multidisciplinary field, able to involve multiple areas in the design process and to relate the various aspects of the contemporary (Maldonado 1976) – can take on the fundamental role of potential social, ethical, and ideological control of contemporary technologies. Therefore, the task of monitoring and leading our evolutionary course and of designing, perhaps even reversing the same technologies, the experience of new sustainable figured realities should be given to design, which has the necessary tools to prefigure new visions and alternative scenarios.

In particular, when we talk about assistive technologies for sensory disabled people, design must deal with a huge complexity due to the fact that they involve a fundamental aspect of our survival: the senses. Our senses allow us to fulfill our needs as biological organisms, to enter into full symbiosis with an information-rich, three-dimensional environment and interact with it. In these cases, technology takes place between the user and their surroundings, right to the point at which symbiosis is undermined, making it quite simple to overcome the threshold between help and substitution, especially in a world in which Artificial Intelligence is able to perform human-like intelligent behaviors. That leaves it up to design to put in place tactical creativity and strategy in order to apply the contemporary technological possibilities in a sustainable way, improving the user's condition and giving him the possibility to overcome the lack (or impairment) of any conventional sense, like sight, touch, and hearing, or of the other senses related to it, like the social sense, the sense of freedom, and the sense of self cognition [3].

3. From science to technology: the premises for innovation.

The sense that puts us in relation with our external environment more than any other is sight. Of all the sensations perceived through our senses, those received through sight have by far the greatest influence on perception. Sight, combined with other senses, mainly hearing, allows us to have a global perception of the world and to perform actions therein. Thus, for the blind, the lack (or impairment) of vision is a major barrier in daily living: information access, mobility, finding one's way, and interaction with the environment and with other people, among others, are challenging issues.

For this reason, and for the possibilities given by current technological advancements such as the miniaturization of electronic components or the development of sophisticated algorithms, the last quarter of century has witnessed a dramatic rise in interest in the development of advanced technological solutions for visually impaired people, transforming them into a sort of human cyborg. In fact, international research and industry are developing countless wearable and portable assistive devices that colonize a blind person's body and that, thanks to the new ability of advanced autonomous systems to simulate the human mind's processes, often replace the user in carrying out daily tasks that are harder to accomplish without sight. Every effort is being made to face this "social phenomenon" [4] and to improve the quality of life of the blind in contemporary society, focusing both on more traditional research fields like those regarding the transmission of the information and mobility assistance and new areas like those regarding computer access, recently added to the list due to the increasing importance of computers and their presence in every aspect of life. As such, apart from the successful Braille reading tool, numerous information transmission devices concerning reading, character recognition, and rendering graphic information about 2D and 3D scenes have been created; classic white canes are being equipped with Electronic Travel Aids (ETAs) or replaced by wearable or portable devices for mobility that involve spatial information regarding the immediate environment, orientation, and obstacle avoidance; and technological solutions like voice synthesizers, screen magnifiers, and Braille output terminals are becoming more and more popular and allow blind people to use computers and access all of their services, such as the Internet. In general, all of them attempt to communicate and exchange information with the environment, other people, or other devices and to translate them in feedback systems that involve other senses, like hearing or touch.

In particular, concerning blind mobility aids that aim to improve orientation and spatial cognition or to avoid obstacles, we can first divide them into two major categories separated by a slight difference: portable devices that can't be worn but which require constant hand interaction, and wearable devices, which (thanks in particular to their small size) can instead be worn on many different parts of the body and give users the possibility of interacting with them in multiple ways without using their hands.

The most common portable devices (Fig. 1) are electronic canes, with the combination of classic white cane and ETAs, but this category also includes tactile displays, mobile phones, independent ETA devices, laptop computers, and so on. ETAs (Fig. 2) are portable devices that all share the same operating principle: they all scan the environment (using different technologies like ultrasonic sensors or cameras) and then display the information gathered to other senses, mainly touch and hearing, like in the case of EyeCane (Fig. 3), a virtual walking cane which emits infrared rays to translate distance into auditory and tactile cues enabling the user to sense objects within an adjustable range of up to five meters. When ETAs are combined with classic white canes, we now have technological canes (Fig. 4) which, compared to traditional ones, are implemented with a set of sensors and multi-sensory displays. These aim to give further information about the surroundings, for example concerning more distant environmental features or the presence of obstacles, landmarks, or hazards at shoulder or head height, like in the case of Ultra Cane (Fig. 5). Thanks to an ultrasonic sensor, this cane can find objects in front of the person and indicate their direction and distance with a tactile feedback (vibration). The very recent phone apps developed by Microsoft (Seeing AI) and Cognitive Assistance Laboratory (NavCog) also belong to the category of portable devices, since the phone must be carried and requires interaction with the hand that moves it and focuses on the environment from various angles. In this case we are talking about AI systems that are able to perform sophisticated smart behaviors, to learn a comprehensive overview of the external environment and even to describe it in detail. For example, the iPhone app for indoor navigation NavCog (Fig. 6) achieves accurate localization using a novel algorithm which combines Bluetooth Low Energy (BLE) beacons with smartphone sensors and allows blind people to find their way inside buildings and in large, complex places such as universities, airports, and hospitals.

On the other hand, the class of wearable devices is more complex and includes all smart systems that interact with different parts of our body (Fig. 7) and use different sensory feedback depending on the condition. From the top down, first of all we have Head-Mounted

Devices (HMDs) (Fig. 8) such as headsets, headbands, helmets, and eyewear that are the most popular kind of wearable assistive devices. In fact, the ears, responsible for the sense of hearing, the one most suitable for replacing the loss of sight, are located on the head and users can use head motion to explore the external environment and gather information from it (Fig. 9). Although many, such as Orcam MyEye (Fig. 10), are developed to access information, we can also find numerous devices developed not just for mobility and focused mainly on spatial navigation and movement, but also on obstacle avoidance at head height. The Horus wrap-around headband (Fig. 11) can provide useful help. Through machine learning and 3D imaging, it is capable of promptly alerting the user of obstacles and directions. Thanks to a voice synthesizer, the device narrates the images seen through bone-conduction- based [5] earpieces. Although it has been developed to avoid obstacles, Sonar Glasses (Fig. 12) can alert the user with vibrotactile feedback about potential hazards that are beyond the reach of a white cane, such as parked vehicles, overhanging branches, street and traffic signs, construction scaffolding, and other obstacles on the ground.
Ears are not the only organ involved thus far. Based on certain studies carried out in 1998 at the University of Wisconsin (USA) that proved that the brain eventually processes visual information by first stimulating the nerves in the tongue, the TDU (Tongue Display Unit) has been introduced which can translate optical images picked up by camera into electrotactile stimuli on the tongue. From this research, several TDU prototypes have been developed. The most recent, as well as the only TDU device that has been produced, is BrainPort V100 in 2015 (Fig. 13).
Going further down, we can find wearable assistive devices for the wrist and arm (Fig. 14) and vest, belt, and foot technologies. They have the same objective: to improve mobility for the blind by avoiding obstacles. They are able to collect information from the external environment and to communicate them to the user, in general haptically, in order to avoid the use of headphones that can isolate the user from the external environment and provide detectable and understandable feedback. For example, in 2017 the start-up WearWorks (Brooklyn), in collaboration with the blind athlete Simon Wheatcroft, developed a navigation device that can be worn on the wrist to allow blind athletes to cover a course unaided and unassisted. The product is called Wayband (Fig. 15). It collects data from GPS maps then communicates the route through a haptic feedback in a sort of Morse Code. Finally, less recent but equally interesting, is the prototype of the shoe-integrated vibrotactile display (Fig. 16) developed at Panamerican University (Mexico) which shows how the vibration encoding through feet is simple to understand, especially if it involves simple directional instructions (e.g. “turn left” or “go forward”) and familiar patterns (e.g. phone call, caution) (Velasquez 2010).
The list goes on and on, and we could go on to describe AI systems that work more or less in the same way which are developed to improve the quality of life of blind people, although they may run the risk of emphasizing the new technological possibility too often at the expense of

the user's actual role. In particular, the fact is that, in spite of so many available devices, user acceptance is low (Cuturi et al. 2016). Blind people still prefer white canes to technological Blind Mobility Aids because, as with Braille, they require active control from the brain, which interprets body movement combined with the information derived from audio or tactile signals which helps them learn to interpret the surrounding world even in the dark. In fact, these inventions are like an extension of the user's hand, allowing users to empower themselves and their sense of touch without losing their attention or self-control. However, this does not mean that we should give up on today's technological advancements, but rather re-evaluate the co-evolutionary relationship between humans and technology when we apply them in devices. We must do so in a way that helps humans evolve and survive to the greatest extent possible, satisfying their needs, empowering rather than blocking them, and expanding their senses rather than blunting them.

The complexity and the autonomous behavior of the majority of the devices listed above places the user in a particularly awkward situation. The user must passively rely on the device's feedback, wandering randomly with hesitant steps, trying to interpret the device's feedback, and continuously questioning the success of single actions. They far outweigh the threshold for replacement and attempt to explore the world on their own, to build a representation of it based on the information that has been gathered and to give certain commands to the blind user, whether they are more direct (like "turn left," "turn right," or " be careful, there is an obstacle") or in the form of detailed descriptions. Instead, new sustainable devices, which are in line with human instincts and capabilities, should first consider human nature so that the mechanisms forming the base of our orientation and mobility derive from a neuroscientific point of view.

This is what we have attempted to do during the development of Sinapsi. The design expresses the emerging ethical, social, and ideological issues arising from the misuse of today's technologies and turns them into design tools to trigger sustainable innovation in the field of assistive devices for sensory disabled people.

4. The rediscovery of a great mentor.

This is where the contemporary border between nature and technology can prove to be a powerful tool for design. In fact, the biological world has been evolving for 3.8 billion years and has encountered the same complexity as today's anthropic reality long ago, so much so that nature has already developed interesting methods and strategies to confront it. Therefore, biology can be a point of reference for design culture as a theorical and pragmatic means for monitoring and leading our evolution so that the ability to incorporate biological characteristics into machines and objects becomes an instrument to improve quality of life and expand our greatest human qualities.

From the hologrammatic metaphor of the system of life to the individual survival strategies developed by countless living beings, nature, as opposed to our artificial sphere which is becoming more and more controllable and manageable, is showing us the secret of hidden wisdom. Indeed, if it is true that, with the technologies available today, we are able to create living artifacts as an organism, it is equally true that we cannot always achieve the same success. In other words, artificial systems are able to contain and manipulate information like organisms, but they are not always endowed with the same intimate intelligence of nature. Regarding Schrödinger (1995), he concludes the definition by specifying that a real organism is "living" if it has been successful in the process of the self-organization of information, namely in structuring information in an increasingly complex and holistic manner, in respect of the whole system in which it is inserted and in order to obtain a coherent behavioral response to the context in which it occurs. This is what is called the "hologrammatic principle" and it is the basis of all complex systems and all languages, principles, strategies, logic, and mechanisms that allow nature to realize and maintain its creatures alive. Therefore, from a methodological point of view, it can be useful to understand and reproduce them in new technologically advanced materials, products, services, and systems not only to resemble living beings, but especially to adopt genuine innovative behaviors, capable of adequately responding in a sustainable and holistic way to all the issues with which they enter into symbiosis (e.g. the user or the cultural or environmental sphere).
With Sinapsi, the hologrammatic metaphor has been applied from the very beginning: the product is seen as a new living being that is going to fit into a "symbiotic ecosystem" that is the blind user's body, sensory organs, and nervous system. In order to achieve this goal, all aspects of the device have been designed and developed in a coherent and integrated manner with the spheres that they came into contact with, such as the user, their perception, self-control, and the ethical issues concerning the autonomy of technology, as well as the issues related to the usability or intelligibility of the sensory feedback. First of all, the design starts from the fact that humans, as animals, must establish a close relationship with their environment through spatial cognition, a special ability that allows us to explore the world through senses, to build a representation of it through our brains (which process the information gathered), and consequently to move in space and perform specific tasks [6]. Therefore, the moment in which sight, the dominant sense that gives us 90% of perceptual information from external and extra-personal space, goes missing (or is damaged), the biggest problem is not avoiding obstacles or finding one's way, but rather the lack of adequate sensory feedback that can properly represent the environment in one's brain (Gori 2017). For this reason, Sinapsi aims to empower the blind to explore the surrounding world with other senses (which is what we do from birth with sight) so as to provide the opportunity for their brains to develop a representation of the world based on the other selected sense. This sense will become dominant and ensure constant feedback in everything they do.

What better way to find a suitable solution than to mimic a strategy developed in nature? Animals, in fact, have the same need to know when and where to stay and move in the environment. They have therefore already developed certain skills and tactics that allow them to have spatial cognition, even in the dark, when the conditions require it (nightlife, living on the seabed, etc.). Among the countless systems studied, the echolocation of bats was considered the most suitable mechanism from which to take inspiration for the new device. In fact, bats emit ultrasonic chirps (sound signals) and then listen to and analyze changes in the return echoes (given by the reflection of sound waves on surrounding objects). In this way, they can understand the shape of the surrounding space and identify the position of negative factors (such as obstacles) to avoid and positive factors (such as prey) to focus on. Furthermore, the approaches that bats take with echolocation are incredibly diverse. There are around a thousand different species that can assume different "echolocation behaviors" according to varying ecological conditions. This ensures that this mechanism is flexible and adaptable to all situations that may arise. Moreover, some studies have demonstrated how echolocation applies to the human brain (Thaler and Castillo-Serrano 2016), and through the brain activity scans of echolocation experts, how the sense of hearing doesn't seem to be simulated but is repurposed by parts of the brain that are normally used for vision (Thaler et al. 2011). However, our bodies and brains have evolved to see the world with sight. We are therefore neither optimally equipped for echolocation nor able to instinctually elaborate information gathered from it. A learning biomimetic assistive device, like Sinapsi, is therefore useful as it provides the blind the tools to develop their own capabilities as well as new strategies to achieve a spatial cognition of their own and, consequently, certain specific navigational skills that make them truly independent and self-sufficient.

5. Sinapsi in greater detail.

As we have stated, Sinapsi is a wearable assistive device which has been inspired by nature, to help blind athletes' mobility and orientation in track and field, empowering them to run without a guide. Sinapsi is also a "learning device" that gives them the opportunity to learn the special mechanisms of echolocation, allowing them to explore and "see" the world in a sort of three-dimensional soundscape.

The field of sports is helpful for these kinds of processes, both because it is important that the feedback is constantly combined with body movement [7] and because it involves training, competition, objectives, discipline, sociability, and respect.

Concretely, Sinapsi is a small, practical device (Fig. 17) that can be worn on the hand and can be connected through Bluetooth to a pair of headphones [8]. When a race starts (Fig. 18), thanks to an accelerometer, Sinapsi automatically takes a photo of the track whenever it is tilted to 60 degrees and simultaneously sends a Bluetooth signal to the headphones that will emit a first tone, which will always be the same. At the same time, sophisticated algorithms (primarily an image recognition algorithm) analyze a group of photos (Fig. 19) while a second tone, simulating the return echo, is created. Depending on the distance between the trajectory of the athlete's foot (diagonal of the photo) and the white line of the track, the device regulates the delay after the first tone while the frequency is regulated depending on the color found at the center of the picture (Lab nomenclature [9]). The result is that a second Bluetooth signal is sent to headphones which creates a second tone that is different with regards to the first as an echo, thereby providing information with it.

The sound design is obviously inspired by the echolocation mechanism of bats, specifically by the way in which they perform perceptual and localization tasks and by the types of chirps (audible signals) they use depend on the ecological conditions and their sensory-motor dynamics (Fig. 20), in order to make the feedback more natural and intuitive, to the extent possible. In particular, the localization task is simulated when Sinapsi communicates the distance with the delay of the second tone. In fact, as in nature, echoes require more time to return when the distance is greater. The characterization task instead, is simulated when the product changes the frequency of the second tone to indicate the color of the track (useful for example for future signage), an exercise that bats can perform with an exceptional ability with regards to the material and the surface texture of a potential target [10].

Finally, as nature teaches us, we can say that something is "living" if it is flexible and adaptable to different situations, existing and in progress. Therefore, we decided to complement Sinapsi with an app in such a way it can be more interactive and multifunctional. It can adapt to different user needs and preferences or to different types of disabilities, and it can be implemented and improved in the future, evolving like a living being. We chose to keep the product as an open concept that leaves space for future ideas and implementations that today can give blind people the perception of a track, of its dimension and its curves, but perhaps tomorrow can give them the possibility to perceive all the surrounding world in its most minute detail. This gives these people the possibility to develop special capabilities with their minds and willpower, co-evolving with technology and facing all the ethical issues derived from the potentially threatening symbiosis and co-dependent relationship between the user and intelligent systems that colonize their body and influence their actions and behavior.

6. Conclusions.

In the "A.I.fication" era, design changes from a simple shape maker to the manager of all the ethical and ideological implications derived from a new "Next Nature" full of thinking entities, capable of empowering yet at the same time replacing humans in understanding and in interacting with the world. In particular, inspired by the natural methods of managing complexity and given its transversal culture, design assumes the role of potential social control of technologies, trying to identify the thin line that separates the sustainable potential of a particular technology from the nightmare of its domination. This is what we tried to achieve with Sinapsi, a wearable device for blind athletes, inspired by the mechanism of echolocation that bats use to move in the dark. We aimed to prevent the “cyborgization” of sensory disabled people, who are increasingly passively dependent on autonomous systems, and to give them the opportunity to empower themselves, developing the special ability to orient themselves without sight using their own minds and willpower.

07. Footnotes

1 - The word literally means “systematic treatment of an art,” indicating a body of knowledge that can be applied as a pragmatic means in all human activities.

2 - The Ancient Greek term for “doing.”

3 - Neurologists have counted between nine and twenty-one unique human senses. Apart from sight, hearing, touch, taste, and smell, we can consider proprioceptive sensitivity, vestibular equilibrium, and the sense of self cognition for example.

4 - The scientific community defines disability as a “social phenomenon” because it is not limited to the physiological lack of a human ability, but it is related above all to the consequences which this lack leads to in contemporary society and which influences the daily life of disabled people (Zanobini and Usai 2008).

5 - Bone conduction is a new technology increasingly used for earpieces that directly stimulates the tiny bones in the ear with small vibrations, allowing the user to hear audio from the device without headphones inside the ears and without interfering with the surrounding noise and disturbing other people.

6 - The representations created by the brain are continually updated while moving and are fundamental because the brain plans the motor activities we can do for achieving a specific task based on these representations (Schinazi, Trash, and Chebat 2016).

7 - “The most fascinating part of the story is that as soon as Ascidia ceases to move, it begins to ingest its brain: without movement there isn’t any need for a brain.” Rodolfo Llinás (2001) stated this to explain that without movement there is no need for a brain, because we are motor animals and action always precedes the sensation and therefore the process of representation.

8 - A set of interviews to blind athletes revealed the need to provide users the free choice of what type of headphone they would like to use.

9 - Lab color space mathematically describes all perceivable colors in the three dimensions: L for lightness and A and B for the contrasting colors of green-red and blue-yellow. We can

consider these three parameters as the three axes of a 3D Cartesian diagram and each color corresponds to a single point of this three-dimensional space (cube).

10 - Thanks to ultrasound, bats are able to understand the material and the surface texture of the target with the same minute detail we can see using a microscope.

08. Figures and tables

(Fig. 1) The diagram summarizes the most common Portable Devices for blind people and the sensory feedback they use.

(Fig. 2) The diagram shows the most used technologies by ETA devices to sense information from the external environment and communicate them with sensorial feedback.
1. Mini Guide (Jacquet et al. 2006); 2. Supersonic Stick (Kim 2010); 3. CyARM (Ito et al. 2005); 4. EyeCane (Buchs et al. 2014; Maidenbaum et al. 2014); 5. Munivo (Giubega 2010).

(Fig. 3) EyeCane, resulting from the research from the lab of Professor Amir Amedi, from the Department of Medical Neurobiology at the Hebrew University of Jerusalem, in 2014. (Retrieved from: https://shacharmaidenbaum.wixsite.com)

(Fig. 4) The diagrams show some example of Technological Canes developed in recent years, as well as the technologies most used for sensing information from the external environment and communicating them with sensorial feedback.

1. The Eyesight (Song 2009); 2. Viio Travel Aid (Halim 2012); 3. LaserCane (Bolgiano and Meeks 1967); 4. Mini-Radar (Dakopoulos and Bourbakis 2010); 5. K-Sonar Cane (Bay Advanced Technologies Ltd. 2016); 6. iSONIC (Kim et al. 2009); 7. Tom Pouce (Hersh et al. 2006); 8. Télétact (Hersh et al. 2006);

9. Navigation Aid for Blind people (Bousbia-Salah et al. 2011); 10. Kinetic Cane (Takizawa et al. 2012); 11. Guide-Cane (Borenstein and Ulrich 1997); 12. Roji (Shim and Yoon 2002); 13. Ultra Cane (Gassert et al. 2013); 14. Mygo Cane (Ritzler 2007).

(Fig. 5) Ultra Cane, developed by a small team of University of Leeds in 2013.

(Fig. 6) NavCog, iPhone app developed by the Carnegie Mellon University Cognitive Assistance Laboratory in collaboration with IBM Research in 2017. It helps visually impaired people to navigate inside buildings and at large, complex places such as universities, airports, and hospitals.

(Fig. 7) Intelligent devices are becoming more and more intimate and can be worn on multiple parts of our body. In particular, wearable technologies for blind people developed to date are in a position to cover the user’s entire body, from head to toe.

(Fig. 8) We can differentiate four major classes of head-mounted assistive devices: headbands (elastic bands around the head), helmets, eyewear, and headsets of different sizes. In this case, sound is the most commonly used sense for feedback, given the proximity of the device to the ears.
1. Blind Guiding Glove (Chen 2012 - Patent: CN202496448);
2. TouchSight (Davies et al. 2007 - Patent: GB 2448166);
3. Tacit (Bat Glove) (Frink 2013); 4. HandSight (Stearns and Smith 2012); 5. Guide-Glove (Castillo et al. 2010 - Patent: MX2009001705); 6. Ultrasonic substitute vision device (Backer et al. 2008 - Patent: GB2448166); 7. Ultrasonic blind-guiding glove (Yang et al. 2008 - Patent: CN201076033);
8. Cyclops (SaloniKidou and Savvas 2012 - Opensource).

(Fig. 9) The operation and the technologies used in head-mounted assistive devices are very similar to all the others. The difference is that they use mostly auditory feedback.

(Fig. 10) Orcam MyEye is an advanced wearable device for the blind. Thanks to a smart camera, it is able to read texts, recognize faces, and identify products, colors, and money and inform the user through an auditory description (voice).
(Retrieved from: https://www.orcam.com)

(Fig. 11) Horus, head-mounted wearable aid for the blind and visually impaired developed by Swiss start-up Eyra in 2016.
(Retrieved from: https://www.designboom.com)

(Fig. 12) Sonar Glasses, developed by the G-Technology Group (USA) in 2018.
(Retrieved from: http://www.g-technologygroup.com)

(Fig. 13) The BrainPort V100 oral electronic vision aid,produced and approved by the Food and Drug Administration (FDA) in 2015.

(Fig. 14) The diagrams show some example of wearable devices for the wrist and arm developed in recent years, as well as the technologies most used to sense information from the external environment and communicate it with sensorial feedback.
1.Tactile Display Prototypes (University of British Columbia 2006); 2. Wayband (WearWorks 2015); 3. Sunu Band (Sunu Inc. 2015); 4. VibroTac (German Aerospace Center and Sensodrive Inc. 2011); 5. Project Bee (Tao Lin et al. 2010)

(Fig. 15) Wayband, developed by the start-up WearWorks (Brooklyn) in 2017.

(Fig. 16) Shoe-integrated vibrotactile display developed by Ramiro Velasquez and his team at Panamericana University (Mexico) in 2010.

(Fig. 17) Sinapsi, a small and lightweight wearable device for blind athletes, implemented with an elastic string that ensures effective hand grasp and designed in two versions, the black version for congenitally blind people and the white one for partially sighted people (sensible to light variations and so a white object can be visible to them).

(Fig. 18) Operation diagram of Sinapsi.

(Fig. 19) Elaborating the pictures with sophisticated algorithms (primarily an image recognition algorithm).

(Fig. 20) Diagram that summarize the echolocation activity performed by bats.

(Fig. 21) The app coupled with Sinapsi: it allow to adjust the spectrum of sound; to regulate the type of echolocation; to listen instructions; to find the device and so on....

09. References

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