Designing Wearable Bio-Interfaces: A Transdisciplinary Articulation between Design and Neuroscience

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Abstract. This paper presents and discusses the rapprochement between Design and Neuroscience in the design of wearable bio-interfaces based on the contributions of studies related to the environment/behavior/neuroscience paradigm and emotional processing in the human brain, regarding the identification and recognition of neurophysiological information relevant to projectual practice in Design. The article also considers the Design-Neuroscience relationship in the projectual practice of wearable computers "BioBodyGame" (2006-2008) and "NeuroBodyGame" (2008-2010) by means of which it addresses the interaction between the body of the user (neurophysiological signals and brain waves) and the computer by the use of bio-interfaces.

Keywords: Design, Neuroscience, Wearable Bio-Interfaces, Transdiciplinarity.

1 Design-Neuroscience Relationship

Neuroscience, as a relatively new science[1], deals with the development, chemistry, structure, function and pathology of the nervous system [11]. In this perspective, cognition is investigated based on the properties of the brain, that is, by assigning specific brain structures to all forms of behavior and experience, even though approximately. Thus, changes in brain structure imply changes in behavior and experience. In this context, if on the one hand, there is the association of bio-based properties to cognition, on the other hand, mental and biological phenomena are considered as products of the cognitive system structure [18].

Researches in Neuroscience [2], [5], [7], [9], [17] indicate that the human brain is particularly able to design things - concepts, tools, languages and locations. In other words, the human brain may have evolved to be creative - to imagine new ideas, put into practice what was invented, and critically analyze the results of human actions.

The cognitive science has already uncovered cue recognition information that designers can apply, for example, "knowing that physical cues located below eye level are more readily processed and attended to than those located above it, wayfinding cues that designers place in our lower field of vision are likely to be most

[1] "Thorough scientific researches on the neural function have a relatively short history, beginning in the late nineteenth century" [11].

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effective" [20]. And in this way the neuroscience literature seems to indicate that the higher purpose of the brain's environment system is to develop a clearer sense of who we are in relation to our environment" [20].

In this context, John Zeisel proposes The Brain's Creative Development Spiral diagram comprising that when someone has a perception, develops a plan or reacts to the environments, the mind uses the same interactive process that designers use in their design process. And, in this sense, Blass suggests that designers and researchers should take advantage of the brain's natural creative process to achieve their ends and that understanding brain function can provide insight into the nature of research, design and creativity. Therefore, exploring the brain even further must improve design and research in practice [20]. For these researchers, the focus lies in answering "how the brain's fundamental creative process engendered the cognitive process of design?" [20], once incorporating an understanding of the brain's neuronal structure and processes Design leads to the most supportive setting for creation and projectual proposals. In other words, "understanding of brain capabilities employing a neuroscience approach reinforces and explains studies of users' needs, behavior, attitude and opinion" [20]. Such understanding also supports the structuring by Zeisel regarding the Environment/Behavior/Neuroscience (E/B/N) paradigm assuming that changes in the environment change the brain and behavior and later the interaction between environmental stimulus and behavioral response in ways that inform and improve design. According him if you understand how people's brain and mind develop and function in different situations, and how they have evolved over time to respond to physical environments, then environments designed to support these capabilities as well as tasks, activities, and user's needs will contribute to people's quality of life, creativity and survival [20]. Thus, while the user's needs paradigm primarily rests on analytic interpretation of externalized data, the neuroscience paradigm rests on analysis of brain and mind based on observed behaviors and adds understanding of neurological and biological functions to traditional psychological, sociological and anthropological environment-behavior knowledge. The goal is that further neuroscience understanding of brain abilities will help designers more effectively plan their projects.

2 The Role of Emotion in Human Survival

One of the brain skills we are interested in addressing and relating more specifically to the projectual practice in Design consists of human emotions. Therefore, at first, we consider this question from the standpoint of neuroscience and neurophysiology so we can propose the articulation of this scope to the field of Design of wearable bio-interfaces in the next section. According to the biological perspective, emotion can be defined as "a set of chemical and neural reactions underlying the organization of certain behavioral responses that are basic and necessary to the survival of animals" [14]. Thus, emotions are essential so the animals can present "appropriate behavioral responses to certain situations, increasing their chances of survival" [14].

On human beings, emotions result from the activation of a complex neural network that promotes a varied repertoire of behavioral responses. In this sense, emotion reaches a subjective dimension of unique experience different from the behavioral dimension observed in other animals. Thereby, on human beings, emotion has a "neural substrate that arranges responses to emotional stimuli and the own perception of emotion" [14]. Although "the precise composition and dynamics of emotional reactions are shaped by each subject, according to the environment and singular development, there is evidence that most emotional reactions, if not all, result from a long history of particular evolutionary adjustments" [4]. As claimed by Damasio, emotions consist of actions or movements that occur on the face, voice or in specific behaviors, many of them are externalized [5]. Nevertheless, despite some of these behaviors that are not visible to the naked eye, current scientific probes such as the determination of blood hormone levels or patterns of electrophysiological waves can make them visible. On the other hand, feelings are necessarily invisible to the public because there is a private ownership of the body hidden from anyone except the one who possesses it.

On human beings, the emotions are mediated within the limbic system by the amygdala and by areas in the hypothalamus, septal area, thalamic core, anterior cingulate cortex and limbic association cortex [10]. Amygdala plays a vital role in social behavior, interpreting facial expressions and social cues [19] and triggering emotional experiences from the electrical stimulation [10]. It receives information from all sensory systems and connects with the orbitofrontal cortex and the anterior cingulate cortex. Together, the amygdala, orbitofrontal cortex and anterior cingulate cortex regulate emotional behaviors and motivation. As a result, it is possible to notice that there is no single brain center for processing emotions, in contrast, there are distinct systems related to separate emotional patterns. In other words, "different emotions are produced by different brain systems" [4].

Human emotions can be classified into three types: (A) primary emotions, (B) secondary emotions; and (C) background emotions. Primary emotions (A) are considered innate or not learned, that is, common to all subjects of the species, regardless of any sociocultural factors. Despite the disagreement among researchers of emotion, there are six primary emotions: joy, sadness, fear, disgust, anger and surprise [14], [4].

Secondary emotions (B), however, are more complex and depend on sociocultural factors. Guilt, shyness, embarrassment, jealousy or pride are examples of emotions that vary in accordance with culture, previous experience and time in which the subject lives. This type of emotion is likely to change; while some civilizations can excessively experience them, others may not even present them [14]. As a consequence, learning and culture alter the expression of emotions and give them new meanings. However, despite the endless variations found in different cultures, among subjects and over the course of a lifetime, it is possible to predict that certain clearly dangerous or valuable, internal or external, stimuli will produce certain emotions [4].

Background emotions (C), on the other hand, are related to well-being, malaise, calm or tension and are usually induced by internal stimuli of regulation of life. Such emotions can also be triggered by physical or mental continuous processes or interactions of the organism with the environment, or by both, leading the body to a state of relaxation or tension, fatigue or energy, well-being or malaise, anxiety or apprehension. Such processes entail "continuous satisfaction or inhibition of impulses and motivation" [4]. While these emotions are expressed in complex musculoskeletal changes, such as subtle variations in body posture and global configuration of movements, the main role is played by the internal environment and viscera [14].

The understanding of emotional variants that comprise the human organism is added to the understanding of its dual biological function. The former consists of the production of a specific reaction to the inducing situation and the latter covers the "regulation of the body's internal state so that it can be prepared for the specific reaction", that is, "certain orchestrations of reactions to a given cause in a given environment" [4]. In this context, chemical and neural commands follow two routes: (D) bloodstream and (E) neurons. In the bloodstream (D), the commands are sent in the form of chemical molecules that act on receptors on cells constituting the tissues of the body. In neurons (E), the commands "take the form of electrochemical cues that act on other neurons, muscle fibers or organs (such as adrenal gland), which may release its own chemical substances into the bloodstream" [4].

As a consequence, although the origin of these commands is limited to a relatively small area of the brain that reacts to a specific content of the mental process, both the brain and the body are affected in a comprehensive and deep way by the coordinated group of these commands, resulting in a global and deep change in the state of the body and the landscape of the body and brain. In compliance with Damasio, all of these changes will constitute the substrate for the neural patterns that will become feelings of emotion, ultimately [4].

3 Designing Wearable Bio-interfaces to Organic Interactions

The transdisciplinary articulation among concepts arising from the neuroscience studies discussed above, particularly related to the environment/behavior/ neuroscience paradigm and emotional processing in the human brain, and the field of Design dedicated to the design of wearable bio-interfaces presents a fruitful process to the research and implementation of direct interactions between the body of users and contemporary computing systems, herein called as organic interactions. This section discusses this potential by means of the projectual practice used in the development of wearable computers: BioBodyGame (2006-2008) and NeuroBodyGame (2008-2010) designed by Rachel Zuanon and Geraldo Lima.

According to Poissant, interfaces are becoming more natural, and may take, alternately or simultaneously, extensible, enlightening, rehabilitative and filter functions or act as agents of synaesthetic integration [15]. In the opinion of Bureaud, interfaces seen as sensory organs generate a deconstruction of the usual modes of perception, as a kind of fragmentation/displacement of the body that leads to reflection on these modes of perception, to questions about the nature of space in which this body exists and fundamentally redefine itself as human [1]. In her view interfaces also work in the "rehabilitation" of forgotten, neglected or lost sensuousness. They restore or reinstate ways of perceiving, differently inciting connection with others and with the world, but first they enable the rediscovery of dimensions and body functions that have become obsolete [15]. In this context, there are wearable bio-interfaces as "agents of stable mediations between thought and matter, thought and sensibility" [15], and the notions of complexity, affectiveness and naturalness are enlarged to an organic scale, in which the physiological information of the users act as data to configure an interaction that responds to their emotional state in order to match the state of their body specifically at that particular moment. The bio-interfaces build a differentiated condition of interaction governed by the biology of the users and include the studies related to functional biometric interfaces, as well as brain-computer interfaces, both focused on enabling communication processes between humans and machines and/or humans-machines-humans based on a co-evolutionary[2] relationship of biological and technological systems [21].

Functional biometric interfaces, based on checking ANS (autonomous nervous system) variability, provide information about the physical state or the behavior of those who use them, continuously gathering physiological data, that is, without interrupting the user activity. For such, biosensors are used as input channels for a functional biometry system, such as: galvanic skin response sensor (GSR); blood volume pulse sensor (BVPS); breathing sensor (BS); and electromyogram sensor (EMG) [21].

In this context, BioBodyGame [22] constitutes a wearable, wireless interface for functional biometric interaction with onboard games in the system, in which the games, as well as the wearable computer, react to the user’s emotion during interaction. For such, the interactor’s neurophysiological parameters are read during playability: emotional variability; anxiety control; emotional response; sympathetic and parasympathetic nervous system; functional oxygen; and cardiac variability. The mapping of these parameters is done and associated in real time to game functionalities, which begin to react in accordance with the player’s neurophysiological state.

Anxiety control is the ability that the subject has to adapt to surrounding stressors, both physical and psychological. This neurophysiological parameter is directly associated with the neuro-emotional reaction and neuro-emotional response that the user of BioBodyGame shows when interacting with the game. In other words, the reaction of the interactor’s autonomic nervous system to external stimuli generated by the environment in which the user is located (neuro-emotional reaction), such as sounds, noises, smells and visual and sensory perceptions, and the response of the autonomic nervous system to internal stimuli (neuro-emotional response) generated

[2] Co-evolution is the selective reciprocal interaction between two major groups of organisms, with a close ecological relationship [13]. According to Moraes, "the co-evolution of biological and physicochemical systems created the conditions for the development of human beings, which introduced a new kind of interaction: human interaction" [12].

by thoughts, feelings, emotions, as well as to its own stimuli generated by neuro-emotional reaction. The analysis of anxiety control, neuro-emotional reaction and response is performed according to the electro-dermal response associated with the sympathetic activity of the user, captured by the galvanic skin response sensor (GSR). The analysis spectrum ranges from 0 to 100%, and the largest percentage indicates better anxiety control by the interactor.

The measurement of the variation of functional oxygen in the blood and heart rate variability - which is determined by the activation or inhibition of the Autonomic Nervous System (ANS) of the user - and the functional analysis of the ANS are carried out by the blood volume pulse sensor (BVPS), in which the pulse, speed, frequency and variability of the optical signal are collected.

The index of baroreflex provides an analysis of the variation of functional oxygen in the blood in a range varying from 0 to 100%, given that the larger percentage indicates normal physiological variation, that is, no significant signals of respiratory changes and cognitive and/or concentration wearing of the user of BioBodyGame.

The index of heart rate variability enables the analysis of heart rate variation according to the degree of stimuli to which the subject's heart undergoes; the reference ranges from - 4 (minimum) to + 4 (maximum), taking into consideration that 0 (zero) indicates the cardio-normal functional activity.

Sympathetic and parasympathetic ranges and the sympathetic and parasympathetic frequencies altogether provide functional analysis of the Autonomic Nervous System. Considering that the indicator ranges of the individual capacity of sympathetic and parasympathetic systems for autonomic performance and the indicator frequencies of the balance between these two systems by autonomic stimulus. Sympathetic and parasympathetic ranges are the intensity of the performance of sympathetic and parasympathetic systems, respectively, and vary from 0 to 100%, where zero indicates the lowest intensity and a hundred represents the highest. While the sympathetic and parasympathetic frequencies indicate the amount of stimuli sent by ANS to trigger the sympathetic and parasympathetic activities, respectively, and vary in a range from 0 to 100%, where zero indicates the lowest intensity and a hundred represents the highest. Nevertheless, sympathetic and parasympathetic ranges and frequencies imply an inversely proportional relationship. For example, the closer the parasympathetic range is of 100%, the better the performance and/or capacity of the subject's ANS. However, the closer the parasympathetic frequency is to 100%, the smaller the stimuli sent by the ANS to the Parasympathetic System. Thus, within the frequencies, autonomic balance is indicated by index equal or close to 50%.

Therefore, in BioBodyGame, the identification and real-time analysis of all these neurophysiological indices by wearable computer are as in Table 1.

In other words, playability is facilitated or made difficult based on the user's emotional state as well as how the wearable computer interprets these emotions and reacts to them, altering their color (front/back) and applying vibrations (back). Thus, a really calm user will have its playability enhanced and the BioBodyGame will mostly react by displaying the color blue. If the user is just calm, the color displayed is green. A tense or even nervous user will have its playability worsen and the wearable bio-interface will react to it by turning into yellow and applying a soft vibration in the back area of the user. And a really tense user will have its playability worsen and the BioBodyGame will react by changing its color to red and by intensively vibrating.

The context of functional biometric interfaces presents even more complex perspectives when brain signals are the substrate of biological information. A brain-computer interface (BCI) transforms the electrophysiological signals of central nervous system activity reflections into the products intended for that activity: messages and commands that act in the world. It transforms a signal, such as an EEG rhythm or a neural trigger rate from a brain function reflection into the final product of this function: an output that, as an output in conventional neuromuscular channels, carries out the person's intention. A BCI replaces nerves and muscles and produces movements with electrophysiological signals associated with the hardware and software that translates them into actions [21]. In this sense, the NeuroBodyGame [23] consists of a wearable computer that allows the users to play games with their brain signals. It is a wearable wireless interface for the brain to interact with the games bundled in the system. It has an independent and non-invasive BCI integrated to its technological system in which the brain output channel is the EEG, and the generation of the EEG signal mainly depends on the user's intention, and not on the peripheral nerves and muscles [8], [16], [6]. This BCI captures the user's brain activity as spontaneous inputs from EEG rhythms on the frontal lobe through two electrodes disposed on F1 and F2 channels according to 10-20 Standard.

Table 1. BioBodyGame – Correlates among physiological parameters mapped, wearable computer and game

Measured Neurophysiological Indexes	**BioBodyGame's Response**	**Game's Response**
- Anxiety Control (Neuro-Emotional Reaction and Response): **≥90%** - Variation of Functional Oxygen: **≥90%** - Heart Rate Variability: **0 (zero)** - Sympathetic and Parasympathetic Ranges: **≥ 80% and ≤ 100%** - Sympathetic and Parasympathetic Frequencies: **≥ 45% and ≤ 55%**	Alteration in appearance, it turns blue	Easy playability
- Anxiety Control (Neuro-Emotional Reaction and Response): **≥ 80% and <90%** - Variation of Functional Oxygen: **≥ 80% and < 90%** - Heart Rate Variability: **≥ +1 and < +2** - Sympathetic and Parasympathetic Ranges: **≥ 60% and < 80%** - Sympathetic and Parasympathetic Frequencies: **> 55% and < 70%**	Alteration in appearance, it turns green	Satisfactory playability
- Anxiety Control (Neuro-Emotional Reaction and Response): **≥ 70% and < 80%** - Variation of Functional Oxygen: **≥ 70% and < 80%** - Heart Rate Variability: **≥ +2 and ≤ +3** - Sympathetic and Parasympathetic Ranges: **≥ 40% and < 60%** - Sympathetic and Parasympathetic Frequencies: **≥ 70% and < 90%**	Alteration in appearance, it turns yellow and there is a soft vibration in the back of the user	Poor playability
- Anxiety Control (Neuro-Emotional Reaction and Response): **< 70%** - Variation of Functional Oxygen: **< 70%** - Heart Rate Variability: **>+3 and ≤ +4** - Sympathetic and Parasympathetic Ranges: **< 40%** - Sympathetic and Parasympathetic Frequencies: **≥ 90% and ≤ 100%**	Alteration in appearance, it turns read and there is an intense vibration in the back of the user	Hard playability

The NeuroBodyGame (NBG) includes, as a BioBodyGame's upgrade, the mapping and the association of user's brain activity in real time to game functionalities, which begin to react in accordance with the player's neurophysiologic state. In other words, playability is facilitated or made difficult based on the user's brain wave frequencies as well as how the wearable computer interprets these brain activities and reacts to them, altering their color (front/back) and applying vibrations (back).

Specifically, the user's brain activity in a frequency period of 9 to 13 Hz enhances the user's playability and the NBG mostly reacts by showing the color blue. The detection of brain wave frequencies between 14 to 21 Hz displays the green color and for frequency periods between 22 to 30 Hz the user's playability is made more difficult and the NBG reacts to it by turning to yellow and applying a soft vibration in the back area; while brain wave frequencies between 31 to 40 Hz make the user's playability even more difficult and the NBG reacts by changing its color to red and by intensively vibrating. It is worth noting that in both wearable computers (BBG and NBG) the games are open source – a fundamental characteristic for providing full remodeling of the programming and integration with the games' controls and the neurophysiological signals and brain wave activity of users.

The design of these two wearable computers assumes that "emotion and biological mechanism are the mandatory monitoring of the behavior, conscious or not" [4]. In other words, some level of emotion will necessarily follow the thoughts that the user has about itself and what surrounds it [4]. Thus, "the thoughts and emotions affect the functions of all organs. This is due to the bidirectional communication between the nervous system and the immune system" [11]. In this regard, an individual reaction to experiences may disturb homeostasis[3]; and set up a response to the stress responsible for increasing strength and energy of the body in order to handle with the situation. In compliance with Lundy-Ekman, three systems create the response to stress: somatic nervous system, autonomic nervous system and neuroendocrinological system. In this condition, the motor neuron activity increases muscle tension (somatic nervous system); sympathetic activity increases blood flow to the muscles and decreases blood flow to the skin, kidneys and digestive tract (autonomic nervous system); the sympathetic nerve stimulation of the adrenal medulla causes the release of epinephrine into the bloodstream. Epinephrine increases the heart rate and cardiac contractile force, relaxes intestinal smooth muscle and increases the metabolism (neuroendocrinological system) [11]. In this context, a concept of significant importance and which also permeates the making of the four pieces as a whole is found in the possibility of it being used by bodies of diverse biotypes. It means that these wearable computers can be expanded or contracted in order to fit in the user's body. Its main challenge lies in the fact that it tries to preserve the user's comfort. Once each and every possibility of discomfort may alter the neurophysiologic signals,

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[3] Homeostasis describes a set of "regulatory processes and, at the same time, the resulting state of a well-regulated life"[4], such as: find energy sources; incorporate and transform energy; maintain, inside the body, a chemical balance compatible with life; replace the subcomponents that age and die in order to maintain the structure of the body, and to defend the body from disease processes and physical injury.

and by doing so, it would compromise the organic information (neurophysiological signals) acquired. And the guiding concept for distribution of all items in these two wearable computers lies in considering that its internal structure reproduces the interior of the human body, taking the brain as the main point from where the nerve stimuli responsible for the body functioning depart and arrive. Therefore, the electrodes and sensors responsible for measuring the user's neurophysiological signals are located in the front view of these wearable systems. Thus, with the human body as a reference, along the spine and medulla, the pieces reproduce the chain of electrical conductors which allow sending information to other areas of the wearable devices. "We are now providing clothes with more complex functions. Clothes become a sensor for recording body information and increasingly exchanges with the environment" [15].

Such articulations between concepts based on Neuroscience and Design to the creation and development of these four wearable bio-interfaces involve a transdisciplinary team comprised of designers, artists, doctors and engineers, which provides the encounter and unique exchange of knowledge among areas fully articulated and integrated to the product's final result.

4 Conclusion

From the Environment/ Behavior/ Neuroscience (E/B/N) paradigm it is possible to understand a closer relationship between the brain's natural creative process and the cognitive process of design. Among the brain skills, human emotions are responsible for profound and global changes in the state of the organism and the landscape of the body and brain, and therefore play a regulatory role in survival. In this sense the neuroscience understanding of brain abilities and human emotions can improve design researches and practices helping designers to plan their projects considering how people's brain and mind develop and function in different situations and then contributing to people's quality of life, creativity and survival effectively. Thus the transdisciplinary articulation between Neuroscience and Design proves to be a promising field of research and projectual development by indicating the way to an increasingly natural interaction between the human body and the contemporary computer systems, that is, in synergy with the human body - both physically and functionally. In this regard, the understandings arising from the environment/ behavior/neuroscience paradigm and emotional processing in the human brain herein addressed in the form of a dialogue with the design of wearable bio-interfaces expand the projectual potential of wearable computers as well as the future prospects of human-computer-environment communication. By offering wearable bio-interfaces for different biotypes and preserving the comfort, the wearable computers BioBodyGame and NeuroBodyGame not only provide a differentiated relationship between the subject and technology, founded on reading, interpreting and associating neurophysiological data to control commands. They allow a meeting between biological and technological systems for collaborative creation, including users with different cultural behaviors, modes of perception and apprehension of the world, altering the expression of emotions and giving them new meanings. As a result, the collaborative work among designers and neuroscientists has proven to be crucial to support and base the transdisciplinary research that effectively cooperates and contributes to the progress of projectual solutions and development of products able to identify and respond appropriately to the organic and emotional needs of the user.

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