The Body and the Mind "through the Lens" of Music: exploiting Brain-Computer Interfaces and Embodied Music Cognition to Assess Sensorimotor Synchronization and Developmental Disorders

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I am working on a report with my computer, and in the meanwhile, I am listening to the radio. I start feeling emotionally engaged with a new hit that the speakers have just started playing. After some time, I recognize I am typing rhythmically: my fingers hit the keyboard following the song's tempo. At the end of the track, I have written twice as fast as I would have done if I could not have felt any music.

Therefore, assuming the presence of some type of consistent path connecting perception, emotion, and action, if they are able to work cooperatively, they achieve better performances. Given this premise, my research addresses the following points.

- Is it possible to use non-invasive technology to identify the presence (and the consequences) of a disruption in the path that links perception, emotion, and action?
- How can designers exploit the coupling of perceptual, affective and motor aspects to improve interaction features and to better support the user?

To partially provide an answer these questions, two aspects will be discussed: the feasibility of a proposal for an unconventional model for assessment methods, and the achievement of better performances through elicitation of users' affective involvement. Indeed, perception and motion are strictly related (Iberall, 1995) (Repp, 2004), as well as perception and emotions are (Preston & de

Waal, 2002) (Scherer et al., 2001). Apparently, there is less connection between affect and movement. Although there is an extensive amount of studies in the literature, the links between Perception, Action, Cognition and Emotion (PACE) still represent a challenging issue to be explored (Juslin, 2000) (Livingstone, 2005) (Camurri et al., 2003).

1.1 - Motivation of my research

The motivation of my research has to be considered from two aspects. First, I have a purely analytical-speculative objective that is, holistically assessing the perceptual dynamics of the brain (in connection with action) by means of non-invasive methods. Also, there is a functional interest in exploiting the primary source of information of the body in a performance-oriented fashion (specifically, the less explored features of the human brain) to improve the outcome of current interactive systems, and to enforce the potential of novel paradigms, such as Physical Computing and Brain-Computer Interfaces.

2 - Perception, Action, Cognition and Emotion

As argued by Berthoz (1987), perception is more than sensing, it is simulated action. According to this view, our brain would create an embodied, in-mind environment whose role is that of a test-bed for our everyday physical experiences. Simultaneously, perception allows us to “see beyond” the tangible cues and the proximal characteristics of the world: we are able to extract affective information that drives our actions towards an objective that renders them meaningful.

In addition, we can use faculties, such as imagination, to envision new situations by processing the building blocks of previous experiences (Johnson, 1987). This in turn, enables us to craft our intentional actions using tools, such as moral judgments and conscience, until we produce the intended action to be exerted.

In this perspective, the concept of intentionality assumes a fundamental role in the connection between perception, action, cognition and emotion.

2.1 – Intentionality of perception, affect, and action

According the evolutionary view based on the process of natural selection, perception and action are *intentional*, in the sense that they are both activated to accomplish a final goal, and their valence (i.e., positive or negative) is evaluated with respect to the achievement of such objective. In the post-Scholastic idea proposed by Brentano (Smith, 1994) at the end of the nineteenth century, intentionality (which derives from the Latin verb *intendere*, which means being directed towards some goal or something) gives a new perspective on humans' behavior and, more generally, it can be utilized to understand the course of the evolution, and the strategic role that perception, action, cognition and emotion plays in natural selection.

Neuroimaging technology allowed scientists to discover the presence of affective states that are biologically inbuilt within species (e.g., calm, fear) (Preston & de Waal, 2002). Researchers identified how emotions are experienced as a consequence of specific features of sensory stimuli (e.g., safety, presence of danger or predator). Also, the presence of motor strategies (e.g., relaxation, alertness) as a reaction of the affective valences of specific situations can be observed in nature (Preston & de Waal, 2002). Findings from several studies confirmed what psychological assumptions based on the evolutionary theory had hypothesized when psychologists envisioned that perception, patterns of movement, and activation of emotions have a genetic nature.

The physiological evidence provided from naturalist theories triggered new studies that led to novel and multifaceted models. As a result, in the last decades, attention moved from the Gestalt psychology towards more robust approaches based on the study of the underlying dynamics of perceptual systems. Indeed, the basic categories of good forms introduced by Wertheimer, Kohler and

Koffka (e.g. proximity, similarity, and continuation) still offer interpretative elements that apply to all sensory channels.

Simultaneously, there is an increasing interest in understanding the underpinnings of perception and action, and in discovering the brain processes that control the close relationship between sensing and cognition. In the last decades, many addressed the traditional mind-body separation from a new point of view, the so called *embodied* approach.

2.2 - Embodiment

As perception, which is originated from the senses, has an intentional nature that can be manifested into actions, it is embedded in a flow that has a bodily nature. Moreover, as both perception and action are fundamental for survival, many argued that cognitive abilities and sensorimotor dynamics must be strictly linked. Also, cognitive processes can be considered as based on motor acts and on Gibson's affordances (Gibson, 1986). The evidence of the presence of close relationships between cognition, motion and perception has fostered the development of the *embodied* argument.

The *embodied* approach provides an unorthodox but increasingly popular view of the nature of cognition: although the ongoing debate has been inspired by diverging positions, there is a common tendency to overcome the Cartesian relativism in which the mind is an entity that acts separately from the body. Instead, the emerging *environmentalism* proposes that the mind is embedded in a body that needs it to function (Wilson, 2002). This perspective is different from the traditional view in which:

- cognitive processes deal with abstract information;
- connections with the physical world only have a background (contextual) role;
- physical variables are not considered in approaching the problem.

In the embodied perspective, cognition is a situated process (Wilson, 2002), that is, *hic et nunc* (ecologically speaking). This is consistent with Brunswick's work, and particularly with the *duplicity* *principle*. The issue regarding the role of the body in the coupled "*mind-body*" system, which initially was originated as a psychological theory, connects cognitive sciences and biology, especially if it is regarded in terms of perception-action (i.e., grounded in the sensorimotor system).

Ultimately, the mind, which is responsible for the perception-action (as an entity embedded in a body), is oriented towards an objective. As the intention of movement contains the mental prototype of the performed action, it is also the intended (voluntary) action that is driven by intentionality. Hence, cognition, affect, perception and action have at least one feature in common that is, intentionality. Consequently, the valence of their outcome is evaluated with respect to their activation.

In other words, by means of simulated (perception) or executed (action) performance, individuals create a correspondence from the domains of intentional strategies (i.e., perception-action couples of exploited cues and motor reactions) to the affective domain of represented by a degree (arousal) of success or failure (valence), as shown in Equation 1.

$$intentionality: perception \times action \rightarrow arousal \times valence \quad (1)$$

As a result, they also share (at least) one representational syntax (i.e., arousal and valence). Indeed, the relationship between intention and intentionality is not reversible (not all goal-directed actions, such as perception, have to be driven by intent), as argued by cognitive philosophers and by behavior analysts (Neuman, 2007).

Embodiment has inspired a variety of disciplines, from psychology to robotics, and it has been affecting several research areas, from cognitive science to neurophysiology. For instance, it largely influenced the spatial cognition theory: scientists discovered that the management of spatial representations primarily relies on the sight (visual channel); the sense of hearing (auditory channel) and movement (kinesthetic channel) orchestrate temporal organization.

On the one hand, this task specialization straightforwardly brings in the relationship between movement and rhythm. On the other hand, the idea that perception-action can be represented in a timeline that has both auditory and kinesthetic features, directly remands to the concept of embodied music, represented, for instance, by a ballet scene, or by a musical instrument playing.

2.3 - Embodied Music Cognition

Several assumptions can be drawn from the role that sensory channels play in cognition and in movement. However, the contribution of hearing and kinesthesia to the temporal organization of action suggests the existence of a sort of auditory timeline of motion in which patterns of actions are orchestrated in a targeted fashion (because they are oriented towards a goal). This especially emerges if we think about the features of the most frequently utilized classes of movements. Conscious motor actions (e.g., walking), semi-conscious movements (e.g., breathing), and involuntary muscular contractions (e.g., heartbeat), are all based on cycles. Periodicity inherently involves the concept of rhythm, which in turn, was found to broadly contribute to the organization of the locomotor system (Todd et al., 1999).

Humans (among other beings) do produce rhythm. Also, it can be said that rhythm is a component that accompanies human beings from the beginning to the end of their lives: mammals intimately experience rhythm long before their birth, because they are exposed to the heart beat of their mother, in a multimodal fashion and for the entire period of their gestation. Indeed, rhythm is among the first experiences of their hearing and of their kinesthetic channel. It is immediate to recall that music, which is a remarkable auditory stream, has rhythm as one of its fundamental components.

Embodied music cognition (Leman, 2007) naturally emerges from the consideration that music involves (with different extents) aspects of Perception, Action, Cognition, and Emotion (PACE).

In general, all music-related activities have a crucial role in the human psychophysical development, they promote psycholinguistics skills, and they foster non-verbal communication. The international literature provides a broad overview of the use of music as a therapeutic technique (Backer, 1999) (Smith, 1990). Furthermore, they have a strict connection with sensorimotor synchronization, which is the ability of humans to plan and execute adequate movement according to the perception of external stimuli (Todd et al., 1999) (Piek & Dyck, 2004).

Current studies in neuroscience are giving an increasing importance to music, and they are discovering its extraordinary potential in the orchestration of relevant perceptual and motor processes. Also, recent researches in cognitive science investigated the relationship between rhythm and the human mind, and they pointed out the presence of complex dynamics occurring in the nervous system at both the structural and the functional level (Todd et al., 1999).

2.4 - The Perception Action Model

The Perception-Action hypothesis is grounded in the theoretical idea that perception and action share a common code of representation in the brain (Preston & de Waal, 2002). This theory is closely related to the principle according to which all (intelligent) behavior has to be conceived as a byproduct of the coordination between the sensory and the motor systems.

In motor behavior, perception-action refers to the transient pathways between perceiving the environment and generating an action. It is the physiological equivalent of the psychological perspective view (also supported by Berthoz) of perception as simulated action. Specifically, it regards the lower-level dynamics occurring in the physical structures of the brain and of the body. This, in conjunction with the notion of embodied (or motor) cognition (Wilson, 2002) (Clark, 2008), suggests that cognitive development arises through physical interaction, in a process coupling the human body and the environment. The Perception-Action Model (PAM) introduced by Preston & de Waal (2002) extends the somatic dynamics of perception action to the cognitive level, thus, realizing a further convergence with psychological theories. It focuses on the concept of empathy, which is defined as the shared emotional experience of individuals mirroring themselves into others (Preston & de Waal, 2002). According to the traditional stream, both observed and imagined movements automatically trigger patterns in specific regions of the brain that are in charge of generating locomotor features. In addition to this, the PAM introduces profound affective components, such as empathy, in the perception-action loop. Both the traditional view and the PAM argue that subjects' attention to the circumstance is required in order for the empathic mechanisms to be activated. A wide range of phenomena find an explanation in the PAM, and they are the basis of social behaviors (e.g. reciprocal inclusion and altruism). Moreover, they can be investigated to assess the presence of impairments in verbal communication, mental disorders, and psycho-physiological responses. In addition to situations of induction of empathy, the Peception Action Model may explain the foundations of the findings of studies about emotion suppression, such as the difference between pre- and post-accident emotional reactions in subjects with spinal cord lesions (Hohmann, 1966). The research about the generation of empathy has primarily been focusing the visual channel. Although further research is required, findings suggest that the results obtained in experiments on vision can be extended to the auditory channel.

3 - Music in the body and in the mind

Indeed, music involves not only quantitative concepts (such as tempo and rhythm) that are functional to motor acts: in addition, it consists of qualitative features that require higher cognitive functions to be interpreted into affective states or emotions. Music can be utilized as a tool for assessing the integrity of PACE because it generates (at the perceivers' and at the listeners' sides) processes underlying both motor responses to its metrical (quantitative) structures and emotional reactions to its affective (qualitative) components.

Aldridge (1993) detailed the effects of cognitive deficits, sensorial disruptions and brain damages on musical-evoked responses. Moreover, disorders may influence individuals' ability to interpret regular patterns in auditory signals perceived from the outside world. As a result, the presence of cognitive impairments may lead to locomotor dysfunctions and lack (or discontinuity) of kinesthetic organization, as it can be observed in subjects affected by Parkinson's disease, who show pathologic movement patterns. Conversely, patients with the Alzheimer's disease seem to maintain the integrity of motor features, albeit they show abnormalities in specific psychophysical responses and in the processing of some affective nuances (Aldridge, 1993).

In my research, I suggest to integrate the concepts of the Perception Action Model and of Embodied Music Cognition into a framework for the assessment of sensorimotor synchronization. To this end, spontaneous (improvised) movements of people listening to music can be observed with non-intrusive sensing techniques to infer their conditions. Specifically, one of the goals of my research is to analyze the correlation between individuals' ability in recognizing quantitative features (e.g., rhythm) and their subsequent kinesthetic planning. This may be employed as a performance index of the integrity of the perception-action channel. Also, I propose to proactively integrate music and biofeedback as a therapy, simultaneously with respect to the assessment. A large number of applications can be developed on top of traditional treatment, in order to foster individuals' engagement, and to reduce their frustration, especially in long-term care.

Moreover, mental abilities allow the brain to automatically interpret the emotional content within auditory stimuli (Seifert, 2006) (Chanel et al., 2006) (Anders et al., 2004). Autism and other forms of disorders (e.g., Asperger's syndrome) and age-related dementia (e.g., the Alzheimer's disease) are known to have an impact on the emotional components, but they may not affect the sensorimotor system (Aldridge, 1993) (Piek & Dyck, 2004). In such cases, the disintegration of emotional processes also results in idiosyncrasies in verbal communication (Leman, 2007). To this end, the acquisition of physiological responses to auditory composition may have a crucial role in enabling the elicitation of linguistic information from non-verbal communication, and they may provide a non-intrusive approach to neuropsychological assessment, as discussed by Leman

(2007). This is consistent with the Perception Action Model (which includes empathy as a fundamental intentional component).

As a result, we can distinguish four basic scenarios in which subjects may fall depending on their physical synchronization and their emotional response with respect to music. They are represented in Table 1. The keyword is “attuning” (Leman, 2007), which is a notable characteristic of perception-action and specifically, the ability to converge with the embodied environment.

Table. 1 – Sensorimotor and emotional attuning to music

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">Synchronization</td></tr>
<tr><td>PRESENT</td><td>ABSENT</td></tr>
<tr><td rowspan="2">Empathy</td><td>PRESENT</td><td>normal subject</td><td>emotional disturbances</td></tr>
<tr><td>ABSENT</td><td>locomotor disfunctions</td><td>emotional disturbances
and
locomotor disfunctions</td></tr>
</table>

4 - The brain through the Lens of Music

Indeed, it is possible to diagnose developmental disorders or motor dysfunctions even without the use of any technology. However, I argue that music, in combination with non-invasive sensing systems, can achieve a deeper insight in the dynamics of the embodied mind and it can provide a user friendly interface for diagnostics and for rehabilitation applications. Moreover, such system would enable monitoring the patients and measuring their therapeutic results without giving them the distressful sensation of being tested.

In my research, I aim at realizing sensor-based acquisition of individuals' parameters, both physical and affective. I focus on the use of the non-verbal channel, because, especially regarding the emotional components, this would cut the interference introduced by linguistic labels (Leman, 2007), and it would produce more meaningful results with respect to self-reporting techniques. Non-intrusive technology (e.g., portable devices or wearable equipment, such as accelerometers or biosensors) may be applied to acquire the features and to convert them into judgments that elicit non-verbal response of the listener (Takahashi, 2005). This approach has been explored by many (Lisetti & Nasoz, 2004), but there is still a divide between sensor-based assistive systems and leisure-oriented user-friendly applications (Reddy & Mascia, 2006). The former usually involve a degree of frustration and less engagement, the latter are not designed for the clinical domain.

4.1 – The Lens Model

The Lens Model (Brunswick, 1955) is among the cornerstones of Probabilistic Functionalism (Shepard, 1987). It is a symmetrical representation that quantitatively defines a model for the ecological relationship between an individual and the environment. It can be utilized to correlate the perceptual (cognitive) strategy and the active (expressive) articulation, conceptualized as the performer's and as the perceiver's mental models (see Figure 1). The actual achievement r_a in the Lens Model Equation (see Equation 2) can be interpreted as a measure of the adherence. It represents the matching (G) between the following:

- the subjective interpretative output resulting from a sensory input, or listener consistency (R_s);
- the objective (environmental) intended interpretation, or the performer consistency (R_e).

$$r_a = GR_eR_s + C\sqrt{(1-R_e^2)}\,\sqrt{(1-R_s^2)} \qquad (2)$$

where G is the expected achievement given the knowledge of the model; R_e and R_s refer to the performer's and to the perceiver's model, respectively. The former is a measure of the consistency at the source (i.e., how successful is the intention with respect to the message), while the latter represents the efficacy at the destination, that is, how much of the message (and to which extent) has reached the listener. They are computed as the linear regression between the two sets of cues X_e and X_s (independent variable) and the two actual states (dependent variable). In the second term of the equation, C represents the unmodeled matching, expressed as the correlation between the residual variances (nonlinear components) of the performer's model $\sqrt{(1-R_e^2)}$ and the perceiver's model $\sqrt{(1-R_s^2)}$.

The Lens Model Equation captures the main argument of the Perception Action Model: features in perceptual stimuli convey contents that are immediately observable (proximal); also, they encode an understated meaning (distal) which requires cognitive processing (judgment) to be elicited.

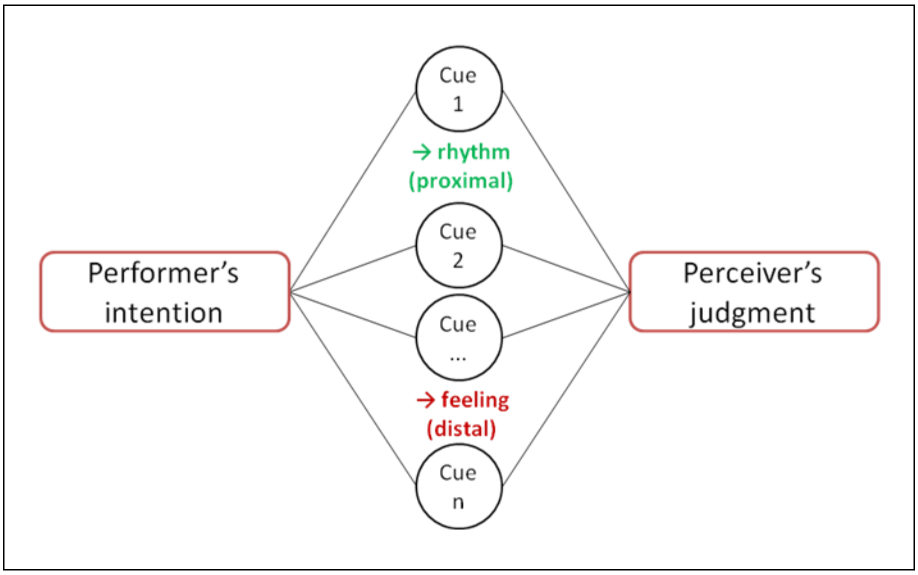

Figure. 1 – Brunswick's Lens Model

With respect to musical performance, Brunswick's Lens Model quantifies the correspondence between the feeling (significance) conveyed by the musical performance and the emotion perceived by the listener along with the notational features (syntax) of the auditory stream.

In the PAM, perceived distal features (those which generate empathy) are translated into qualitative components. They are not represented by quantitative parameters. Instead, the analysis of the achievement in the Lens Model is based on the judgment J, which is an elicitation (i.e., a label given in linguistic terms) corresponding to the output of the cognitive interpretation of the meaning of the transmitted message. However, as argued by Leman (2007) (see paragraph 4), verbal communication can be regarded as a noisy channel, especially in individuals with mental dysfunctions and developmental disorders. Thus, non-verbal information gathered from sensing technology, might be more robust for inferring the judgment.

4.2 – Intentionality and intended actions

Let us consider the relationship between intention and intentionality with respect to Human-Computer Interaction (HCI): the majority of the actions captured by standard input devices are intended, and all of them are intentional by definition (see section 2.2). Regardless of the difference between voluntariness and intentionality, a number of stimuli (perception), movements (action), processing (cognition) and affective states (emotion) occurring during the interaction with a computer, go beyond the capabilities of traditional user interfaces, and thus, they are invisible to the machine.

On the contrary, novel HCI paradigms use sensors to acquire physiological measurements (e.g., heart rate, impedance of the skin), and other features of physical interaction (e.g., gestures, gaze) (Lisetti & Nasoz, 2004) (Takahashi, 2005) directly from the user. They allow to get access to a number of parameters that can be employed to understand the underlying dynamics of PACE, and to shape interaction accordingly. For instance, the heart rate can be analyzed to indirectly infer the emotional state. The so called *affective sensing* systems enable applications that are especially suitable to accommodate the concept of *embodied mind*.

With respect to rhythm-related movement, traditional input devices (e.g. a standard mouse) are suitable for acquiring finger tapping. Nonetheless, several currently available sensing devices support the implementation of applications for physical sensing. Movement captured using inertial sensors (or other technology, such as gyroscopes and intelligent textiles) placed on different locations of the body might include components that are more representative of the current affective state of the subject. Nonetheless, many different instruments, such as microphones and cameras, can capture other features of non-verbal communication. Apart from being non-intrusive, such devices can be coupled with different types of displays to simultaneously provide subjects with multimodal feedback about their performance.

4.3 - Brain-Computer Interface

Among physical sensing systems, Brain-Computer Interfaces (BCI) are gaining attention for their potential to harvest input directly where it is generated, the brain. Non-invasive direct neuroimaging methods, such as electroencephalography (EEG), have a temporal resolution that is suitable to detect potential evoked by perceptual stimuli (e.g. P300 evoked potential), and they can classify emotional states (Horlings et al., 2008) (Khosrowabadi et al., 2009). Moreover, as they do not rely on peripheral nerves and muscles (Wolpaw et al., 2002), they enable interacting without *visible* actions. Besides the potential medical applications, especially in assistive systems for people in conditions of disadvantage (e.g., locked-in patients, individuals with degenerative diseases), BCI is suitable as an unconventional interface for a large number of purposes. Ultimately, they might represent an important conceptual extension to the architecture of embodiment.

To this end, Brain-Computer Interfaces (BCIs) can be employed in combination with other sensing devices that enable multimodal input, in order to rigorously analyze the intended component of both the actual motor component and the imagined movement.

Such novel interaction paradigm is inherently embodied, because it requires the mind to accomplish an intended action by creating a mental feedback of the intentional transition from the internal modulation of the environmental task (i.e., activating brain areas responsible for motor act) to a representation of the ongoing action in the external world (there are no proprioceptors for brain signals, and robots do not offer proper exteroceptors).

In this regard, it integrates the so called *manipulative* and *non-manipulative* strategies (Rowlands, 1999) into a mixed approach in which subjects:

- use their brain signals to convey the intention of an action which is actually realized (or supported) by electromechanical systems, such as computers, robots or prostheses (*manipulative* strategy);
- do not demand the task to others; instead they maintain the control of the action, and their activation is responsible for the achievement of the goal (*non-manipulative* strategy).

Brain-Computer Interfaces (BCIs) translate subject's intentions into a control signal for an electronic device or application (e.g. personal computers, wheelchairs, and prostheses) directly exploiting the potential of the human brain in substitution of the usual human output pathways such as muscles. Recently, BCIs have gained attention as an innovative and effective method which is more powerful than standard Human-to-Machine systems. The main motivation for BCI research is to provide patients having severe neuromuscular disabilities with a new interaction channel towards the outside world. For instance, they can support from simple tasks, such as computer-mediated communication, to complex control of personal computers, electronic appliances, prostheses, and small robots. Nonetheless, Brain-Computer Interfaces may enhance the interaction experience of healthy subjects; consequently, the interest in nonmedical BCIs is increasing due to commercial demand (e.g., video games, automobile industry). Recently, alternative and portable devices for EEG signal acquisition are available at low-cost; they implement a reduced set of electrodes and channels which not suitable for clinical use; indeed it is sufficient for BCI.

Current sensing technology is sufficient for the purposes of BCI, and the acquisition process is stable enough. However, even with the last modern techniques and technologies, BCIs are invasive. Moreover, the design of existing systems lacks of flexibility, leading to applications with high latency, having very slow interaction rates (in the order of 2-3 tasks per minute). To this end, there is a need for efficient BCI algorithms to be run on portable devices (e.g., PDAs or iPhone) and on systems with limited computational resources, so that BCIs could be integrated into everyday life technology. It is my belief that such issues will be solved in the next years.

On the other hand, there is an increasing demand for multimodality in both stimulation and feedback: the majority of brain-controlled systems are based on Visual Evoked Potentials (VEP), and the user is provided with feedback conveyed through one sensory channel only. Such modality limits the potential of current BCI research. Furthermore, individuals who are in need of the support of BCIs may have vision problems: many patients in locked-in state, who are the ideal candidates for clinical Brain-Computer Interfaces, lose their sight due to a lack of hydration of the pupil.

Recently, multimodal feedback has been one of the new research streams in BCI. This is also because, as subjects are engaged in tasks, components of the visual system such as vision, visual attention, and focusing gaze are physiologically employed in the dynamic contact between the user and environment. Indeed, the visual channel needs a complementary method for conveying stimuli and feedback. Nevertheless, only few studies have tested other feedback and stimulation modalities for BCI. Therefore, I argue that multimodality in stimulation and in feedback might be one of the most interesting directions for future work in the context of Brain-Computer Interface.

The design of a framework for multimodal stimulation and feedback is one of the objectives of my research. The embodied paradigm is inherently based on the visual, on the auditory and on the haptic channels. To this end, the properties of information conveyed through different senses have to be considered. One of the key aspects is to introduce ad hoc protocols to avoid collision between stimulation and feedback.

Also, the augmentation provided by Brain Computer Interface to the perception-action mechanism described in the PAM supports the inclusion of music in the framework. Indeed, the analysis of interaction based on mu-rythm may explain underlying dynamics of perception-action in sensorimotor synchronization. Simultaneously, BCIs may provide access to the interpretation of the emotional flow from the performer to the perceiver in terms of empathy with a specific feeling. To this end, the Brain-Computer Interface offers a unique channel for eliciting both the correlation between motor coordination and cognitive disorders (by means of the investigation of both voluntary and spontaneous music-related movement), and the current affective state (thanks to the high temporal resolution capable of capturing changes individuals' brain rhythms). Moreover, this paradigm may also facilitate subjects with deficits affecting verbal communication in revealing their emotions and their potential.

4.4 – A comprehensive emotional representation

Indeed, it is relatively easy to measure the adherence of the quantitative components of movement in relation to a rhythmic pattern. Conversely, the investigation of the emotional domain is a challenging task.

The idea that music conveys emotions is ancient and deeply embedded in humans, as shown in recent studies (Oliveira & Cardoso, 2007) (Mladjenovic et al., 2009). Besides the traditional cognitivist idea that music can simply express emotions, an emerging emotivist perspective, which argues that music can actually produce them, is gaining acolytes. Also, the findings of recent studies again suggest an evolutionary reason for affect that is, they are functional to survival. In this sense, they are intentional. As far as affective elements are concerned, representations in terms of valence and arousal (activation) were developed to describe the emotional content of music (Ekman et al., 1992) (Russell, 1980) (Scherer, 2001).

From an evolutionary perspective, the classification of emotions can be regarded as an integral part of the embodied cognition framework. Indeed, the discussion about the primal source of emotions goes beyond the purpose of this work. Moreover, the so called “nature versus nurture” debate on the origin of emotions dates back to ancient Greek philosophers such as Aristotle and Plato, and no definitive taxonomy of emotions exists (Mcintyre & Göcke, 2008).

In Darwin, emotions appear as innate, as an hereditary equipment that enables to better respond to environmental stimuli (Darwin, 1998). According to this view, behaviors, and particularly emotions, have evolved for their ability to support fundamental life tasks. As a consequence, they have adapted through a selection process which is typical of the physical characteristics of living creatures. Within the stream of evolutionary theory, many argued that the ability to communicate basic emotions (e.g., through facial expressions) is part of the genetic heritage of species, also (Plutchik, 1982). Therefore, evolutionists consider affect as a universal component, in the sense that it goes beyond ethnicity, and it is cross-cultural (Ekman & Friesen, 1971) (Ekman et al., 1971) (Smith & Ike, 2003). On the contrary, culturalists, such as Birdwhistell and Leach argue that communication and emotions are learned along with language (Russell et al., 1989).

Recently, evidence suggested the co-existence of both universals and cultural differences for communicating emotions (Ekman et al., 1987). Ethnographic studies showed the presence of differences due to the cultural influences of a peculiar environment, especially during the developmental age (Russell et al., 1989). However, research confirmed that culture-dependant variations seem to introduce only small modulations to the fundamental components of emotions, in favor of the naturalistic argument. The concept of display rules was developed to take into consideration a contextual layer of culture-induced variations in the ontology of individuals' expression of emotion. Others analyzed the functional dynamics of affective processes, and they aimed at identifying the temporal sequence and the structural organization of groups of emotion.

Damasio (2000) focused on the relationship between emotions and consciousness, arguing that emotions are programmed reactions to stimuli (internal and external). He argued that emotions occur in three steps: perception of the stimulus (perceptual process), analysis of the response (cognitive process), and emotional reaction (bodily process). Conversely, many studies have attempted to identify whether it is possible to analyze perceived emotions using some common dimensions, and to classify them with attributes from a defined inventory (Sander et al., 2005).

A huge body of research in psychology has identified between four and twelve independent basic factors of affect (e.g., degree of anxiety, anger, tension) that can be viewed as distinguishable determinants of emotions (Russell, 1980) (Plutchik, 1982) (Ekman, 1992). This is consistent with the theory of discrete emotional states proposed by Tomkins and Izard, two advocates of evolutionism. The contribution of Darwin's approach emerges in studies that had the aim of overcoming the previous emotion theories, towards a more empiricist idea in which it is possible to find connections with the recent discoveries in the field of cognitive neuroscience and neuroimaging. As a result, several studies focused on the genetic and cognitive underpinnings of affective processing within the Central Nervous System (CNS) (Posner et al., 2005). This is especially true within music: the inherent dichotomy of notational structure (syntactic) and performance expression (semantic) (i.e. rhythm, intensity) has been detailed in a large number of studies. As a result, there are invariant features in musical grammar that are interpreted into live objects producing more empathic feedback.

Over the last fifty years, many models have been developed with the aim of understanding how people feel emotions. In the literature, there are mainly three models to classify the, and especially those induced by music: the categorical model (Ekman, 1992), the dimensional model (Russell, 1980) (see Figure 2), and the component process model (Scherer et al., 2001).

It is my intent to integrate such theories into a unique model that exploits the pros of each one’s specific features, and particularly:

- identification of the basic characteristics of affective states using the fundamental properties introduced by Ekman (1992);
- uniform and accessible representation of emotions in the two-dimensional circumplex space discussed by Russell (1980);
- quantitative composition of the constituents of affective processes, as detailed in Sherer (2001).

Figure. 2 – Two-Dimensional Affective Space

5 - Conclusion

In this chapter, we described the theoretic basis for a non-intrusive assessment technique aimed at observing psycho-physical diseases by means of the analysis of several features within music-induced movement.

My objective is to exploit low-cost, non-intrusive, portable devices in order to acquire information from individuals' non-verbal communication channel. The aim of my proposed framework is to apply a holistic approach, and to investigate the ability in reproducing rhythmic features of music as a mental analog of locomotion, employing a method based on the integration of the Perception Action Model and of Probabilistic Functionalism. The core technology I intend to exploit is Brain-Computer Interface, in association with other physical sensing devices.

The BCI paradigm has already been employed in many multidisciplinary researches, and cognitive science explored its contribution to the recognition of mental states (e.g., both affective and attentive). However, there are still issues regarding its performances, which are suboptimal with respect to their potential. For instance, frustration arising from long and tedious training sessions is one of the most frequently reported drawbacks. With respect to this, it is my belief that one of the main features of BCI (and its less explored potential) is the strong coupling with the brain (in the *embodied* sense), and the deep user awareness that such systems can achieve. To this end, I propose to enforce the link between the emotional components of interaction and the measured performances, in order to realize interfaces being able to proactively exploit the individuals' mental states in supporting their intended action.

I argue that embodiment, as a situated process based on intentionality, could be implemented by opportunely designing an approach oriented towards affective rewards; that is, both the performances and the objective have considered with respect to the emotional descriptors of the current affective state of the user (e.g., valence and arousal). In this regard, as music offers an unconventionally profound perspective on individuals' affective states, it may serve as a probing tool to assess both user's engagement and their disposition towards the task. This in turn, would help shape current interfaces into flexible systems that are able to reconfigure their interaction style according to the mental state of the user. Consequently, they could sense user frustration and take action to prevent individual’s annoyance from degrading the system’s performance (for instance, they can either terminate the session, or change the task).

As a result, by incorporating the concepts of embodiment, Human-Computer Interfaces will become mutually aware tightly-coupled systems. Hence, considering ongoing research (Anders et al., 2004) (Chanel et al., 2006) (Khosrowabadi et al., 2009), I propose a differential analysis of the embodied reactions to the perceived subjective emotional components which are implicitly transmitted along with music, to achieve a better understanding of the affective disturbances typical of certain developmental disorders. In addition to motivate non-verbal communication, the proposed technique may also serve as a therapeutic agent in bio-feedback applications.

5.1 – Closing remarks

This work originates from the work on Embodied (Music) Cognition in its various forms discussed by Johnson (1987), Rowlands (1999), Leman (2007), and by Chemero (2009). Although the name of this work, “The body *and* the mind”, might seem to suggest a contrast with respect to Johnson’s masterpiece’s “The body *in* the mind” (Johnson, 1987) and with Rowlands’ book “The body *in* mind” (Rowlands, 1999), it is not intended to oppose their view. On the contrary, it is meant to signify the invaluable contribution of the environmentalist approach: unifying the cognitive and the physical components into a unique embodied entity. To this end, in the title of this article, the word “brain” is referred to the conceptual-tangible object in which cognition, emotion, perception and action converge into intentionality.

However, I decided for a slight distinction to emphasize that my objective is to exploit the coupling between the body and the mind to simultaneously investigate them as integrated and as separated at the same time. In the literature there is a debate between the cognitivist and the naturalist theories. Indeed, this work follows the approach based on Darwin’s evolutionary theory. Nonetheless, the underlying philosophy is that it is fundamental to incorporate naturalistic and culturalistic theories as two layers (i.e., universal, and individual) of a complex model that comprehensively considers affective behavior, perceptual processes, and motor dynamics as three functional manifestations of intentionality. Although the objective of my work is analytical, rather than conceptual, it requires to be supported by tangible results that will be collected in ongoing studies, and that will be published in follow-up works. Nevertheless, I argue that such multidisciplinary contribution (though it does not provide evidence from direct experimental studies), might be pervasively beneficial to different fields such as computer engineering, psychology, physiology, neuroscience, and music.

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