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Chapter 10

Subjective and Objective Measures

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Abstract. One of the greatest challenges in the study of emotions and emotional states is their measurement. The techniques used to measure emotions depend essentially on the authors' definition of the concept of emotion. Currently, two types of measures are used: subjective and objective. While subjective measures focus on assessing the conscious recognition of one's own emotions, objective measures allow researchers to quantify and assess the conscious and unconscious emotional processes. In this sense, when the objective is to evaluate the emotional experience from the subjective point of view of an individual in relation to a given event, then subjective measures such as self-report should be used. In addition to this, when the objective is to evaluate the emotional experience at the most unconscious level of processes such as the physiological response, objective measures should be used. There are no better or worse measures, only measures that allow access to the same phenomenon from different points of view. The chapter's main objective is to make a survey of the main measures of evaluation of the emotions and emotional states more relevant in the current scientific panorama.

Keywords: Emotions; Measures; Emotional response; Arousal; Valence

Introduction

The biggest challenge in the study of emotions is to measure them because they are related to internal states of the individual. First, it is noted that the emotional response may be of several types, for instance, verbally, through facial expressions, body movements and/or physiological responses. Although there are several theories about emotions, there is agreement on the two dimensions for measuring emotions: *Arousal* and *Valence* (e.g., Lang Bradley, & Cuthbert 1997; Russell & Barrett, 1999). *Arousal* refers to the psycho-physiological condition caused in the individual by the presence of a stimulus, product or object (Lang, 1995). It may be high when the stimulus produces a high activation in the subject (e.g., see a snake) or low when the stimulus produces low activation (e.g., listening to music for relaxing). *Arousal* is characterized by an activation of the autonomic nervous system (e.g., fight or flight reaction), and the activation of the endocrine system (e.g., increased blood cortisol levels) which enable the individual to respond appropriately to the stimuli. *Valence* (Lewin, 1935) concerns to the positivity (e.g., Happiness) or negativity (e.g., Sadness) that a stimulus or situation elicits in the individual.

Existing instruments for measuring emotions can be divided into two major groups: subjective measures (e.g., questionnaires) and objective measures (i.e., psychophysiological).

Subjective measures

One way to measure and evaluate emotions and emotional states is using subjective measures. This type of measures is essentially based on self-reports or questionnaires. A range of different subjective measures is available which reflects the variety of ways in which emotion has been conceptualized. Next, some of the most commonly used subjective measures are described.

The subjective measure most used to measure emotions against a given product is PrEmo. This instrument was created by Desmet, Hekkert, and Jacobs (2000) and aims to measure the pleasantness or unpleasantness that one product elicits in the user. It consists of eighteen cartoon-like images, each image representing an emotion: 9 positive emotions (inspired, appreciative, pleasantly surprised, enthusiastic, attracted, desiring, fascinated, content, and softened) and 9 negative emotions (bored, contempt, aversive, disgusted, dissatisfied, indignant, vulnerable, and disillusioned). The cartoons represent the facial expressions and body postures of each emotion.

The application of this instrument consists of showing the products to the participants. After the interaction with the product, the participant must choose which cartoon(s) that best characterize the emotion felt in the presence of the product. This instrument has a great advantage for the evaluation of emotions elicited by products. Participants do not need to verbalize the emotion experience, since they only have to identify it visually through the cartoons represented in PrEmo. This feature is very important for this type of measures since verbally expressing emotion can prove to be a very difficult task since not all individuals have the necessary vocabulary to do it (e.g., Desmet, Hekkert, & Jacobs, 2000).

Another widely used instrument for emotion self-reporting is the SAM (Self-Assessment Manikin) proposed by Bradley and Lang (1985). SAM evaluates the valence, arousal and also the emotional dominance (subjective feeling of control regarding the emotional event). The three dimensions are represented by a pictogram rating system: the valence is evaluated on a scale ranging between negative and positive dimensions (sad, neutral and happy faces); the arousal varies between calm and active (e.g. from a small beating heart to a heart beating with an explosive/flash appearance); and the dominance varies from submissive to overwhelming dominance (e.g. a picture element that is much larger than the rest). The participants only have to indicate the option that best applies their emotional experience with the object/product, for each dimension. It should be noted that this test only allows access to the general emotional

state of the individual, so for this reason, it is advisable that this test should be applied in conjunction with other measures (e.g., physiological measurements). This test has the main advantage that it is easy to administer, answer and analyze, and, also, the fact that it is cheaper and may be applied on paper or computer. SAM has often been used in human-robot interaction (e.g., Mussakhojayeva, Kalidolda, & Sandygulova, 2017).

Other examples of self-report instruments are: PANAS - *Positive and Negative Affect Schedule* (Watson *et al.*, 1988) which is a self-reported questionnaire consisted of two 10-item scales to measure positive and negative affect and different versions were developed for different purposes (e.g., PANAS-C, PANAS-X); STAXI - *State-Trait Anger Expression Inventory* (Spielberger, 1988) which is developed to measure intensity of anger and the disposition to experience angry feelings and there is a current version STAXI II (Spielberger, 1994); STEM - *State-Trait Emotion Measure* (Levine *et al.*, 2011) which assesses stable and current emotions at workplaces; Affective Slider (Betella & Verschure, 2016) which is a digital self-reporting tool to measure arousal and pleasure on a continuous scale; among others. There are studies in human-robot interaction area used PANAS (e.g., Bucci *et al.*, 2017; Mutlu, Yamaoka, Kanda, Ishiguro, & Hagita, 2009).

Many other techniques have been used in the measurement of emotions, such as the analysis of facial expressions proposed by Ekman and Friesen (1978) and Ekman, Friesen, and Hager. (2002) called *Facial Actions Coding System* (FACS). FACS is a tool to measure facial expressions by dividing facial expressions into individual components of muscle movements. Some robots (e.g., Tutsoy, Gongor, Barkana, & Kose, 2017) are detecting human's emotions by using FACS technique while others (e.g., Loza, Marcos, Zalama, & Jaime, 2013) use FACS to define their own facial expressions.

Ten Emotion Heuristics (Lera & Garreta-Domingo, 2007) is another technique which is dedicated to help measuring the affective dimension in the user evaluations. The heuristics are based on different theories such as FACS (Ekman *et al.*, 2002) and The Maximally Discriminative Facial Moving Coding System (MAX) (Izard, 1979).

Furthermore, other techniques such as analysis of the body movements (e.g., Tracy & Robins, 2004) and vocal expressions/speech analysis (e.g., Juslin & Scherer, 2005) can be used to assess in a more qualitative or quantitative manner.

Only recently, emotions came to be regarded as an important component of cognitive functioning (e.g., decision making), and not just as something that negatively affects rational thought (e.g., Damásio, 2003; Goleman, 1995; Norman, 2004), hence the recent history of

emotions in the field of Design and Engineering. In this sense, one of the most significant developments of emotion in technology was to create products, objects, and machines capable of expressing, recognize and feel/show emotions. That is, it became evident the importance of the individual establishing an emotional and empathetic relationship with the products, through its design, thus giving rise to emotional design.

Despite the relevance of the subjective evaluation of emotional states, it is sometimes necessary to evaluate the individuals' emotional experience in a deeper way, i.e. accessing the internal, cognitive and physiological mechanisms that individuals are not able to report subjectively.

Objective measures

The instruments previously discussed are subjective in nature as they rely on self-reporting. Consequently, what is being assessed with these instruments is the conscious recognition of one self's emotions, i.e. emotions are to certain extends "rationalized". As such, the unconscious emotional processes which can, in some sense, be regarded as "truther" are not being clearly evaluated. Additionally, although such self-reporting measurements are based on scores, they only provide a semi-quantitative assessment of emotions.

The use of objective physiological measures comes then to both quantify and assess the conscious and unconscious emotional processes (e.g., Ekman *et al.*, 1983; Lang, Greenwald, Bradley & Hamm, 1993; Scherer & Wallbott, 1994; Stemmler, Heldmann, Pauls, & Scherer., 2001). As before, the two-dimensional model for emotions: *Arousal* and *Valence* are considered and are now correlated to quantitative physiological measures.

Understanding which physiological measures to consider, one has to understand how emotions are "generated". This issue has not yet a definite answer, is a topic of discussion and research for generations, and often dwelling into the realms of philosophy. Scientifically though, the processes are starting to be understood and have their bases in neuroscience.

The nervous system is intricate and complex information and communication system (see Table 1) (Kandel, Schwartz, Jessell, Siegelbaum, & Hudspeth, 2013). It gathers information from the external environment by making use of senses (sight, hearing, touch, taste and smell) and, similarly, from the internal environment by making use of various bodily sensors such as muscle spindle sensors that provide information regarding proprioception (knowledge of body parts/movement) and pain (e.g. inner organs malfunctioning such as in a heart attack). Stimuli information from the external and internal environments is then communicated to the brain directly via nerves (e.g. optic nerve and facial nerves) or to the spinal cord via peripheral nerves.

Information at the spinal cord is then forwarded to the brain (the brain and the spinal cord comprise the central nervous system) where it is processed and interpreted in complex cognitive and emotional processes, from which result in action that is communicated to other brain regions (e.g. storage of an event into memory), to the face (e.g. triggering the mimicry muscles for smiling) or to the body via peripheral nerves (e.g. informing the hand's muscles to wave goodbye or increase heart rate during running).

Table 1. Simplified organization and roles of the nervous system and its components

System Level	Role
<p><u>Central Nervous System</u></p> <p><i>Brain</i></p> <p>Organs of senses (Sight, Hearing, Taste, Smell) and sense of touch of the face)</p> <p><i>Spinal Cord</i></p>	<p>Information gathering, processing, interpretation, translation into action and communication</p> <p>High-level (cognition and emotion) processing, interpretation and translation into action</p> <p>Gather information from the external environment and forwards it directly to the brain via cranial nerves; gather information from touch, proprioception and pain from the trigeminal cranial nerve; facial mimicry via cranial facial nerve</p> <p>Low-level (muscle and osteotendinous reflexes) processing, gathers/sends information from/to the peripheral nervous system</p>
<p><u>Peripheral Nervous System</u></p> <p><i>Somatic</i></p> <p><i>Autonomous</i></p> <p>Sympathetic</p>	<p>Gathers information from the rest of the body to the spinal cord or to the vagus nerve (autonomic information)</p> <p>Gathers information from the sense of touch, proprioception and pain from the body; convey conscious/voluntary and unconscious/involuntary motor information; also convey motor information to the pharynx (speech)</p> <p>Gathers information and acts upon visceral organs (e.g. heart, lung, gut, bladder), glands, and sex organs; conveys conscious information; regulates pupil diameter</p>

Parasympathetic	<p>Conveys “fight or flight” information; increases pupil diameter; sweating</p> <p>Conveys “rest/maintenance” information; decreases pupil diameter; increases secretion of salivary and lacrimal glands</p>
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* for a more complete view of the nervous system explained in a joyful yet complete way it is suggested the reading of “Clinical neuroanatomy made ridiculously simple” by Stephen Goldberg.

Unlike, cognitive processes (e.g. memory, calculus, navigation, executive functions), which are regarded as being held solely in the brain, emotional processes do have a bodily translation (e.g. when feeling anxious the palms get sweaty and the heart is pounding). In the event of an external (e.g. listening to the favorite music; touching a rose petal) stimuli or internal process (e.g. thought of the loved one), information is further processed in the brain where is emotionally interpreted and then translated into a bodily response.

The emotional communication between the brain and the body is then mediated via the spinal cord and the peripheral nervous system, which includes the somatic and the autonomous nervous systems.

The somatic nervous system communicates both conscious and unconscious brain processes, such as voluntary and involuntary movements. Emotional content is, nonetheless, more often perceived from involuntary movements such as body movements (e.g. gestures, body stances, and postures). The autonomous nervous system, on the other hand, communicates unconscious brain processes only (see Figure 1).

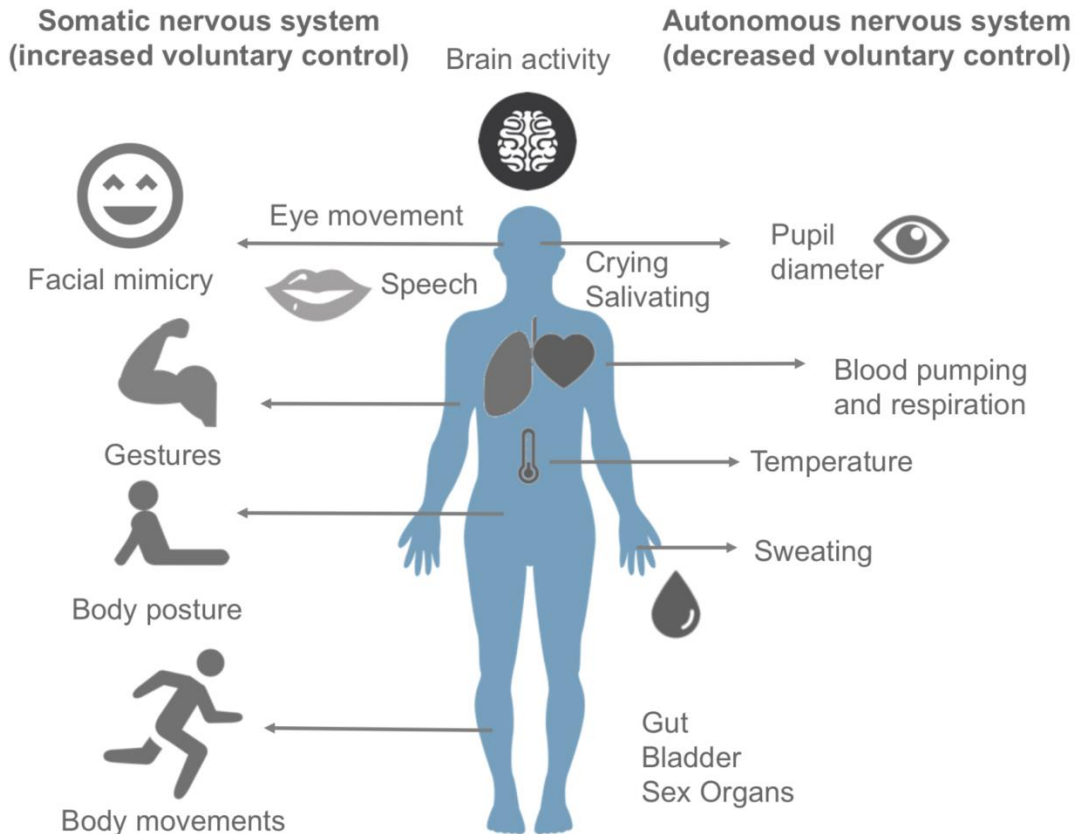


Figure 1. Representation of physiological measures/actions and their relations to the somatic and autonomous nervous systems.

Emotional processing of stimuli in the brain often makes use of evolutionary older brain structures such as the diencephalon (hypothalamus and basal ganglia) and the limbic system but also of evolutionary newer brain structures such as the neocortex. The emotional output is then communicated to the autonomous nervous system which is comprised of sympathetic and parasympathetic systems, which have “opposite” effects. The former system is related to a “fight or flight” or stress reaction, in the sense that prepares the body for action. The latter system is related to a rest reaction as it prepares the body for “maintenance” (e.g. digestion and sleep).

The effect of sympathetic activation (or parasympathetic inactivation) results for instance in increased pupil diameter, heart rate, blood pressure, breathing rate, and sweating as the body prepares to better assess the nature of a threat (increased visual acumen) and makes resources available for action (increased blood flow delivered to skeletal muscles, heart, and head that results in increased local temperature and blushing). The effect of parasympathetic activation (or sympathetic inactivation) oppositely results in decreased pupil diameter, heart rate, blood pressure, breathing rate as the body is being set to a rest state, and also increased secretion of salivary and lacrimal glands.

The autonomous nervous system is a system that can react fast to changing environments and therefore to emotional processes. These processes also elicit the response of the endocrine system which has a much slower but long-lasting effect. For instance, in the event of chronic stress, there is a sustained increase in blood cortisol levels, a process which is mediated via the endocrine system.

Arousal is then understood as a degree of alertness/excitement, and therefore is more directly related to the activation of the autonomic nervous system and the endocrine system, but also to some extent to the somatic nervous system. Consequently, arousal can then be measured more directly in the body. Nonetheless, aspects of arousal can also be translated into facial mimicry (e.g. surprise)

Valence, on the other hand, does not have a simple correlation to the activation of the autonomic nervous system, as stimuli strongly positive or negative could provide similar autonomic reactions. *Valence* can be better perceived from facial mimicry (e.g. fear) and speech and overall from the somatic nervous system body movements/posture and gestures. Also correlates of valence have been described regarding the brain activity, such as pre-frontal alpha wave asymmetry (see below).

As such, *Arousal* and *Valence* can be perceived via different physiological measures which can be assessed using different techniques. A resume is shown in table 2.

Table 2. Emotional dimension, physiological measure and assessment technique.

Dimension	Physiologic measure	Suggest assessment technique
Arousal	Pupil diameter; Eye movement patterns Facial mimicry Speech Heart rate; Heart rate variability Breathing rate and pattern Blood pressure/BVP Temperature "Sweatiness" Brain activity	Eye tracking Eye tracking; EOG Video facial recognition; EMG Voice/sound analysis; EGG; IMU ECG; PPG; Video Piezo/Force/pressure sensors; EMG; PPG; Oximetry Pressure sensor/PPG; Thermometer GSR/EDA EEG; other neuroimaging/physiological techniques (see overall)

Valence	Facial mimicry Speech Body Movements Brain activity	Video facial recognition; EMG Voice/sound analysis; EGG; IMU VIS/IR video (w/ or w/o markers); 3D depth cameras; IMU; EMG EEG; other neuroimaging/physiological techniques (see overall)
Dominance	Brain activity	EEG; other neuroimaging/physiological techniques (see overall)
Overall	Neurophysiologic/ Neuroimaging correlates	fMRI; fNIRS; MEG; PET; BCI; tCS; TMS

*BCI = brain-computer interface; BVP = blood volume-pressure; ECG = electrocardiography; EDA = electrodermal activity; EGG = electroglottography; EMG = electromyography; EOG = electrooculography; fMRI = functional magnetic resonance imaging; fNIRS = near-infrared spectroscopy; GSR = galvanic skin response IMU = inertial measurement unit (accelerometer ± gyroscope ± magnetometer ± barometer); MEG = magneto encephalography; PET = positron emission tomography; Piezo = piezoelectric sensors; PPG = photoplethysmography; tCS = transcranial current stimulation; TMS = transcranial magnetic stimulation; VIS/IR = Visible/infrared. Invasive techniques that require bodily fluid collection such as blood or saliva (e.g. for cortisol level measurement) are not here considered.

Although less studied, the dimension of emotional dominance has also been correlated to physiological measurements, such as beta wave power in the midline brain, a measure of brain electrical activity.

The different techniques to assess the physiological measures are mostly optical, and electrical/electrode or sensor-based (here chemical methods of assessment of emotions via analysis of bodily fluids such as blood and saliva are disregarded). In particular, when the brain or body electrical activities are assessed it is referred to electrophysiological techniques, which will be described in more detail below.

Optical techniques include the use of visible or infra-red video cameras, which may have 3D depth perception, to assess facial mimicry, gestures, postures, and movements. These cameras can further be combined with markers placed on the body for increased precision.

When used for facial mimicry these cameras are combined with recognition/computer vision algorithms based on the Facial Action Coding System (FACS) method. This method codes facial

expressions, depending on involved muscles and was developed by Paul Ekman and Wallace V. Friesen in 1976. Nowadays, the company Affectiva offers a software development kit that facilitates the development and deployment of facial mimicry recognition applications (<https://www.affectiva.com/>) For the assessment of body movement, other algorithms are used instead. Microsoft's Kinect is one of the first and most well-known system for body movement recognition and more recently Leap Motion (<https://www.leapmotion.com/>) developed its controller which recognizes gestures with greater accuracies.

The same Kinect or other video cameras can make use of an algorithm called Eulerian Video Magnification to magnify subtle changes of color of the skin at which heartbeat: due to increased blood flow in the face, the skin is slightly redder. In this manner, it is possible to assess heart rate in a contactless manner (Gambi *et al.*, 2017).

Other sophisticated infrared systems are eye trackers, which have been fundamental in the Design process. These instruments allow to perceive the points in an image or video in which the user fixes his attention and also enable the measurement of pupil diameter, thus informing on the cognitive processes of exploration of an image of a product for instance and the arousal levels such product elicited in the user (Poole & Ball, 2006).

The use of the eye tracker already has more than a century of history, existing records of its use in 1878 (Javal, 1878). However, the first eye trackers were very invasive and dangerous measuring instruments, because to measure the ocular movement, they had to be in contact with the cornea of the participants.

It is estimated that the first non-invasive eye tracker was created in 1901 by Dodge and Cline. However, this instrument was very limited (e.g., participants could not move their heads). Over the years, the eye tracker technique has been improved and used primarily in research and studies on reading.

Its evolution was such that in 1948, Hartridge and Thompson, created the first head-mounted eye tracker. Over the years and as the technology is improving eye trackers have extended their use to other areas of knowledge, such as human-computer interaction (e.g. Josephson & Holmes, 2002; Reeder, Pirolli & Card, 2001).

Eye movements allow the individual to maintain or shift the gaze between various visual areas (Goldberg & Wichansky, 2003) by capturing information that is then transmitted and processed in the brain.

This set of information collected through the eye tracker may prove to be fundamental for the designer to identify the points of the object that most catch the attention of the user, and thus increase them.

Simpler optical systems comprised of light emitting diodes (LEDs) and photoresistors or other photodetectors are used to assess blood-volume pressure (BVP) signals, a technique called photoplethysmography (PPG). BVP signals translate the amount of blood flowing through a vessel and can be used to compute the heart rate and heart rate variability, but also the breathing rate, and a correlate of the blood pressure (see figure 2). In fact, just after a heartbeat, excess blood flow is observed in tissues in a pulsatile manner which will reflect or transmit light differently, enabling it to be detected.

Further development of these systems which include both red and infrared LEDs is oximetry. Besides the former measures discussed above, it can also provide oxygen saturation, translating increased or decreased blood flow in the brain that may result from an emotional response. Finally, temperature can also be assessed using an infrared LED or infrared cameras, as well as with other methods.

Other physical sensors include piezoresistors, and other force and pressure sensors may be used to measure breathing rate and breathing patterns via a flexible sensor strap placed around the thorax. Pressure sensors are typically used for assessing blood pressure, or as microphones can also be used to capture speech, which is then classified by specialized algorithms.

Inertial measurement units (IMUs) explore other physical proprieties of sensors and typically comprise accelerometers, gyroscopes, magnetometers/compass and, also, more recently barometers. IMUs are used to both voluntary and involuntary movement and may be used also to assess speech, via assessing the vocal box vibrations.

Electrophysiological techniques, on the other hand, are used to measure a large variety of brain and body electrical signals, especially associated to emotions and the autonomous nervous system but also to cognitive processes and to the somatic nervous system.

Since it was invented by Hans Berger in 1929 (Berger, 1929), electroencephalography (EEG) has been the technique the neurophysiological technique by excellence, as it measures the electrical activity of the brain (see Figure 2). Both EEG signals and their frequency components (delta, theta, alpha, beta and gamma) have been associated with arousal, valence and dominance (Reuderink, Mühl & Poel 2013):

- Delta (0.5-4Hz): a power increase in the posterior right hemisphere is associated with increasing arousal;
- Theta (4-8 Hz): a power decrease in the frontal cortex is associated with increasingly positive valence and to attention;
- Alpha (8-13 Hz): a global power increase is associated with increasing arousal, additionally, a frontal left-right hemispherical asymmetry correlates with valence with a decrease in power in the left/right hemisphere for positive/negative emotional information, respectively;
- Beta (13-30 Hz): a correlation in the midline with dominance;
- Gamma (>30 Hz): asymmetry in the temporal cortex was found associated with valence.

Additionally, EEG signals have been shown to assess attentive/focused and meditative/resting states. In attentive/focused states an increase in beta power and a decrease in alpha power are observed (Marrufo, Vaquero, Cardoso, & Gomez, 2001). In meditative states, an increase in alpha power in the occipital cortex, and an overall increase in both theta and beta powers were observed (Ahani *et al.*, 2014).

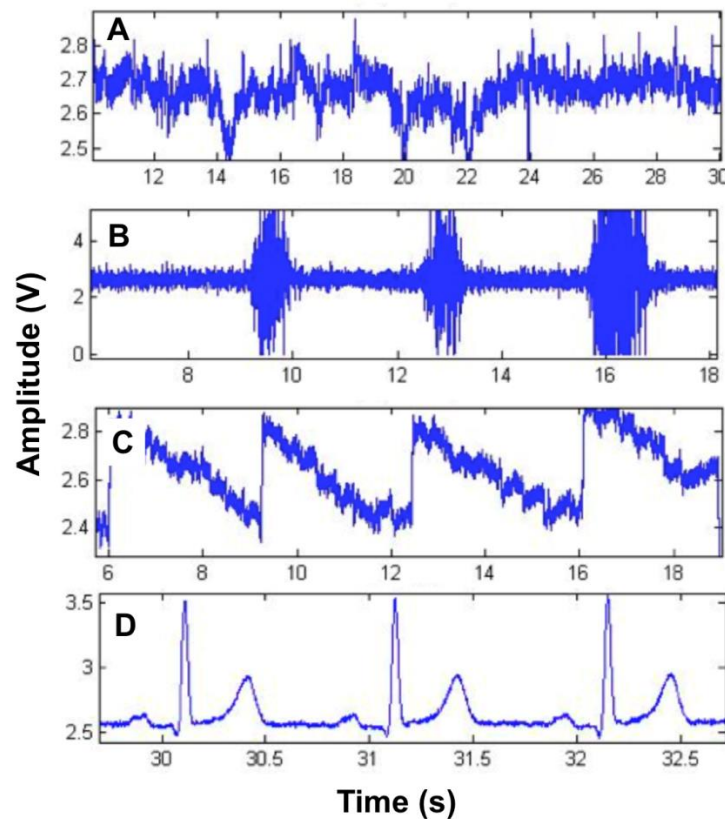


Figure 2. Example of electrophysiological signals tracings: A – Electroencephalography; B – Electromyography; C – Electrooculography; and D – Electrocardiography. (Adapted from: Ribeiro *et al.*, 2014)

Electromyography (EMG) is a technique that translates skeletal muscle activity. It is therefore related to the somatic nervous system and can translate both conscious and unconscious cognitive processes. EMG sensors are typically placed over the facial muscles in order to detect expression related to facial mimicry (Bartlett *et al.*, 1996), but they can also be placed in the upper or lower limbs to perceive movement or event jittery associated to an anxious state (Haag *et al.*, 2004). Finally, EMG sensors can also be placed over respiratory muscles in order to assess the breathing rate, which is under control by the autonomous nervous system. Fast breaths can be associated with high arousal states while slow shallow breaths can be associated with low arousal states. Here, the deepness of breath (as assessed by the amplitude of breathing) can further discriminate between emotions, whereas fast and deep breathing can be related to an excited state, which can be positive or negative in valence, fast and shallow breathing can be related to tense anticipation. Also, slow and deep breathing can be related to a relaxed state, a slow shallow breathing may be associated with depressive syndromes or calm happiness (Haag *et al.*, 2004).

Electrooculography (EOG) measures the electrical activity associated with eye movements. EOG may be used as a complement to EEG for instance for detection of EEG signal artifacts but can also be used to monitor eye movements as scanning of a particular visual stimuli, and detect blinking rate (Calvo & D’Mello, 2010), which may help translate a particular emotional state (e.g. anxiety, withdrawal) and also be used to detect facial mimicry around the eyes (Setz, Schumm, Lorenz, Arnrich, & Tröster, 2009).

Electroglottography (EGG) measures the electrical flow across the larynx which is increased when focal cords are closed. It can be used to depict the emotional content of speech (Hui *et al.*, 2015).

Electrocardiography (ECG) measures the electrical activity of the heart and therefore measures the activity of the autonomous nervous system. It is perhaps the most widely used technique for assessing emotions using physiological signals. These signals can be measured using electrodes over the chest or even on the fingertips using a two-electrode setup. Heart rate (HR) and heart rate variability (HRV) can be easily measured from ECG signals and can translate a state of relaxation when HR is small or HRV is low and a state of anxiety/stress when the HRV is high. A high HR can also translate an excited state (Haag *et al.*, 2004). Finally, ECG signals can also be used for artifact removal in EEG signals.

Finally, the electrodermal activity (EDA), also known as, galvanic skin response (GSR) is also a widely used electrophysiological signal for emotion recognition. It translates skin conductance, which changes accordingly to the skin sweat, as already first studied by German physiologist Emil Heinrich Du Bois-Reymond in 1849. EDA then assesses the autonomous nervous system, especially the arousal level. As such, EDA has been found to be a useful way to assess stress and to differentiate between conflict/no-conflict situations. The main drawback of this technique is its dependence on external factors such as temperature (Haag *et al.*, 2004).

All these signals have been used individually, but multimodal approaches have shown improved accuracies in emotion detection (Kim, Bee, Wagner, & André, 2004). This type of measures involves the application of sensors and electrodes in the individual, so that, although painless and harmless, these methods are more intrusive and more expensive than self-report instruments, but also much more powerful.

So far, considering what was discussed, EEG is the only technique that directly measures brain electrical activity. The other techniques mostly measure the outcome of brain processes communicated to the peripheral nervous system.

More recently, other more complex and expensive neurophysiological and neuroimaging techniques have been used to study emotional processes in the whole brain. In this regard, besides EEG, the magnetoencephalography (MEG) technique is being used for the study of emotions within the millisecond time-scale (Giorgetta *et al.*, 2013). Moreover, when both EEG and MEG are used for high-density recording their output may result in functional images, which may provide advantageous views on the data.

Other functional neuroimaging techniques include functional near-infrared spectroscopy (fNIRS), functional magnetic resonance (fMRI) and positron emission tomography.

fNIRS uses similar technology to oximetry, but sensors are spatially arranged in order to provide increased spatial information. Nonetheless, fNIRS does not provide a direct measure of brain activity, as EEG does. Instead, it assesses the local increased arterial blood flow resulting from the increased demand of local neurons for oxygen and glucose during stimuli processing or during a task (Nishitani & Shinoara., 2013).

fMRI works similarly as fNIRS, as it depends also on local increased arterial blood flow. In this case, though, it makes use of the proton properties of tissues, not the optical properties. fMRI as an imaging technique is able to provide better spatial localization of the brain processes, although being a more expensive and less available technique (Phan, Wager, Taylor, & Liberzon, 2002).

The PET technique is the most specific of all as radiotracers can be designed and used to address a particular metabolic route or neurotransmitter receptor. In this manner this technique has the greatest potential to enable a deeper understanding of molecular and cellular functional processes. Nonetheless, when comparing to fMRI a number of disadvantages have to be equated, such as the invasiveness/need to inject a contrast agent, use of ionizing radiation, longer scan times, less time and spatial resolutions, smaller market availability and higher costs.

These techniques are all related to the measurement of cognitive and emotional processes. Nonetheless, it is possible to study these processes by modulating/manipulating the brain and observing the outcomes. These interventional techniques include EEG-based brain-computer interfaces (BCI) which operate via neurofeedback, exposing the user to a translated version of his/her own physiological measures and enabling the progressive control of such measures (Johnston *et al.*, 2011).

Other interventional techniques include transcranial direct current (tDC) and transcranial magnetic (TMS) stimulation, which both modulate tissue electrical excitability via the application of electrical currents (in the former) and magnetic fields (the latter) (Martin *et al.*, 2018; Notzon, Steinberg, Zwanzger, & Junghöfer, 2017). As being interventional and more recent, there is still a great investment in assessing the safety profiles and effectiveness of such techniques, but the potential of these techniques, particularly, in combination with the other measurement techniques is enormous.

Conclusion

Emotions are ever more a topic of research and, correspondingly of application. As more and more studies put in evidence the critical role of emotions; in what makes us humans like and dislike, love and hate, and motivate, lead and decide; the more important is to have awareness of the subjective and objective tools and techniques that are available and that are being developed for measuring, assessing (also for modulating) emotions. That is so more important in the Design field, as the designer makes use of his/her emotions to dream and create, and the user, as more than a recipient he also co-participates in the design process guided by his/her own emotions, aesthetics and ultimately his purchasing decision.

In this chapter, besides subjective measures, neural-correlates of emotions, related physiological measures, and assessment techniques are described, hopefully in with the right mix of overall perspective and detail. We further hope to have given our reader, the designer

(and other related professionals), additional tools to create ever-more valued products and services.

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