

Chapter 9

Subjective and Objective Measures



Hugo Alexandre Ferreira and Magda Saraiva

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

9.1 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:

H. A. Ferreira (✉)

Faculdade de Ciências, Instituto de Biofísica e Engenharia Biomédica, Universidade de Lisboa, Lisboa, Portugal

e-mail: hugoferreira@campus.ul.pt

M. Saraiva

Centro de Investigação e Intervenção Social (CIS-IUL), Instituto Universitário de Lisboa (ISCTE-IUL), Lisbon, Portugal

© Springer Nature Switzerland AG 2019

H. Ayanoğlu and E. Duarte (eds.), *Emotional Design in Human-Robot Interaction*, Human-Computer Interaction Series, https://doi.org/10.1007/978-3-319-96722-6_9

Arousal and *Valence* (e.g., Lang et al. 1997; Russell and Barrett 1999). *Arousal* refers to the psychophysiological 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).

9.2 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 et al. (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, disappointed, 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) 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 felt, 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 emotions can prove to be a very difficult task since not all individuals have the necessary vocabulary to do it (e.g., Desmet et al. 2000).

Another widely used instrument for emotion self-reporting is the SAM (Self-Assessment Manikin) proposed by Bradley and Lang (1994). 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 pos-

itive 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 to 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., Mussakhojajeva et al. 2017).

Other examples of self-report instruments are: PANAS—*Positive and Negative Affect Schedule* (Watson et al. 1988) which is a self-reported questionnaire consisting of two 10-item scales to measure positive and negative affect with different versions developed for different purposes (e.g., PANAS-C, PANAS-X); STAXI—*State-Trait Anger Expression Inventory* (Spielberger 1988) which was developed to measure intensity of anger and the disposition to experience angry feelings (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 and Verschure 2016) which is a digital self-reporting tool to measure arousal and pleasure on a continuous scale; among others. In fact, there are studies in human-robot interaction area which have used PANAS (e.g., Bucci et al. 2017; Mutlu et al. 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 et al. (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 et al. 2017) are detecting human's emotions by using FACS technique while others (e.g., Loza et al. 2013) use FACS to define their own facial expressions.

Ten Emotion Heuristics (Lera and 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 and Robins 2004) and vocal expressions/speech analysis (e.g., Juslin and 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, recognizing and feeling/showing 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.

9.3 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 et al. 1993; Scherer and Wallbott 1994; Stemmler et al. 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 an intricate and complex information and communication system (see Table 9.1) (Kandel et al. 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).

Unlike, cognitive processes (e.g. memory, calculus, navigation, executive functions), which are regarded as being held solely in the brain, emotional processes do

Table 9.1 Simplified organization and roles of the nervous system and its components

System level	Role
Central nervous system	Information gathering, processing, interpretation, translation into action and communication
<i>Brain</i>	High-level (cognition and emotion) processing, interpretation and translation into action
Organs of senses (sight, hearing, taste, smell) and sense of touch of the face)	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 the cranial facial nerve
<i>Spinal cord</i>	Low-level (muscle and osteotendinous reflexes) processing, gathers/sends information from/to the peripheral nervous system
Peripheral nervous system	Gathers information from the rest of the body to the spinal cord or to the vagus nerve (autonomic information)
<i>Somatic</i>	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)
<i>Autonomous</i>	Gathers information and acts upon visceral organs (e.g. heart, lung, gut, bladder), glands, and sex organs; conveys conscious information; regulates pupil diameter
Sympathetic	Conveys “fight or flight” information; increases pupil diameter; sweating
Parasympathetic	Conveys “rest/maintenance” information; decreases pupil diameter; increases secretion of salivary and lacrimal glands

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

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 Fig. 9.1).

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)

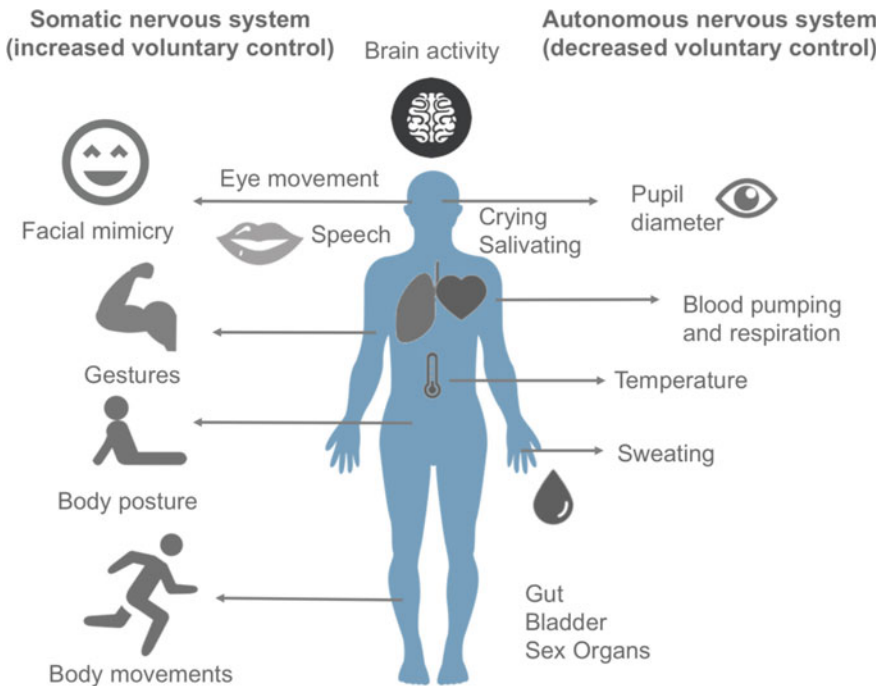


Fig. 9.1 Representation of physiological measures/actions and their relations to the somatic and autonomous nervous systems

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. disgust) 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 9.2.

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 not discussed). 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, companies such as Affectiva offer software development kits that facilitate the development and deployment of facial mimicry recognition applications. 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 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

Table 9.2 Emotional dimension, physiological measure and assessment technique

Dimension	Physiologic measure	Suggest assessment technique
Arousal	Pupil diameter	Eye tracking
	Eye movement patterns	Eye tracking; EOG
	Facial mimicry	Video facial recognition; EMG
	Speech	Voice/sound analysis; EGG; IMU
	Heart rate; Heart rate variability	ECG; PPG; video
	Breathing rate and pattern	Piezo/Force/pressure sensors; EMG; PPG; Oximetry
	Blood pressure/BVP	Pressure sensor/PPG
	Temperature	Thermometer; IR; thermographic cameras
	“Sweatiness”	GSR/EDA
Valence	Brain activity	EEG; other neuroimaging/physiological techniques (see overall)
	Facial mimicry	Video facial recognition; EMG
	Speech	Voice/sound analysis; EGG; IMU
	Body movements	VIS/IR video (w/ or w/o markers); 3D depth cameras
Dominance	Brain activity	IMU; EMG 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*, magnetoencephalography; *PET*, positron emission tomography; *Piezo*, piezo-electric 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

each 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 users focus their gaze 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 elicits in the users (Poole and Ball 2006).

The use of the eye tracker already has more than a century of history, existing records of its use in 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.

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 improved, eye trackers have extended their use to other areas of knowledge, such as human-computer interaction (e.g. Josephson and Holmes 2002; Reeder et al. 2001).

Eye movements allow the individual to maintain or shift the gaze between various visual areas (Goldberg and 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. 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 oxygenated 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) typically comprise accelerometers, gyroscopes, magnetometers/compass and, also, more recently barometers. IMUs are used to assess both voluntary and involuntary movement and may be used also to assess speech, by measuring the vocal box vibrations.

Electrophysiological techniques, on the other hand, are used to measure a large variety of brain and body electrical signals (see Fig. 9.2), 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 neurophysiological technique by excellence, as it measures the electrical activity of the brain. Both EEG signals and their frequency components (delta, theta, alpha, beta and gamma) have been associated with arousal, valence and dominance (Reuderink et al. 2013):

- Delta (0.5–4 Hz): a power increase in the posterior right hemisphere is associated with increasing arousal;

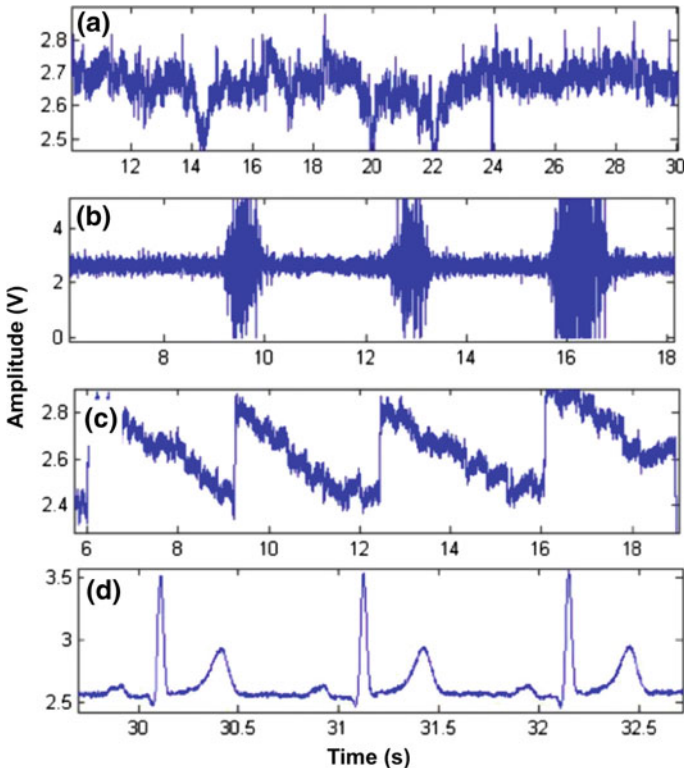


Fig. 9.2 Example of electrophysiological signals tracings: A—Electroencephalography; B—Electromyography; C—Electrooculography; and D—Electrocardiography. Adapted from Ribeiro et al. (2014)

- Theta (4–8 Hz): a power decrease in the frontal cortex is associated with increasing 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 et al. 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 as well (Ahani 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 expressions 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 jitter 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, whilst 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 the 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 and 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 et al. 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 computed from ECG signals and can translate a state of relaxation when the HR is

decreased and the HRV is increased and a state of anxiety/stress when the HR is increased and the HRV is decreased in regards to baseline values (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 et al. 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 and Shinohara 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 et al. 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 has to be equated, such as the invasiveness/need to inject

a contrast agent, use of ionizing radiation, longer scan times, smaller temporal 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 current stimulation (tCS) and transcranial magnetic stimulation (TMS), 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 et al. 2017). As being interventional and more recent, there is still a great investment in assessing the safety profiles and effectiveness of such techniques, but their potential, particularly in combination with the other measurement techniques, is enormous.

9.4 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 (and 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, also co-participates in the design process guided by his/her own emotions, aesthetics and 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.

Acknowledgements Hugo A. Ferreira acknowledges the financial support for writing this chapter from “CAMELOT—C2 Advanced Multi-domain Environment and Live Observation Technologies” Project ID: 740736, funded under the European Commission grants H2020-EU.3.7.3.—Strengthen security through border management H2020-EU.3.7.7.—Enhance standardization and interoperability of systems, including for emergency purposes.

References

- Ahani A, Wabbeh H, Nezamfar H, Miller M, Erdogmus D, Oken B (2014) Quantitative change of EEG and respiration signals during mindfulness meditation. *J Neuroeng Rehabil* 11(1):87. <https://doi.org/10.1186/1743-0003-11-87>
- Bartlett MS, Viola PA, Sejnowski TJ, Golomb BA, Larsen J, Hager JC, Ekman P (1996) Classifying facial action. In: *Advances in neural information processing systems*, pp 823–829
- Berger H (1929) Über das elektroencephalogramm des menschen. *Archiv für Psychiatrie und Nervenkrankheiten* 87(1):527–570
- Betella A, Verschure PFMJ (2016) The affective slider: a digital self-assessment scale for the measurement of human emotions. *PLoS ONE* 11(2):1–11. <https://doi.org/10.1371/journal.pone.0148037>
- Bucci P, Cang XL, Valair A, Marino D, Tseng L, Jung M, Rantala J, Schneider OS, MacLean KE (2017) Sketching cuddleBits: coupled prototyping of body and behaviour for an affective robot pet. In: *Proceedings of the 2017 CHI conference on human factors in computing systems—CHI'17*, pp 3681–3692. <https://doi.org/10.1145/3025453.3025774>
- Bradley MM, Lang PJ (1994) Measuring emotion: the self-assessment manikin and the semantic differential. *J Behav Ther Exp Psychiatry* 25(1):49–59. [https://doi.org/10.1016/0005-7916\(94\)90063-9](https://doi.org/10.1016/0005-7916(94)90063-9)
- Calvo RA, D’Mello S (2010) Affect detection: an interdisciplinary review of models, methods, and their applications. *IEEE Trans Affect Comput* 1(1):18–37. <https://doi.org/10.1109/T-AFFC.2010.1>
- Damáσιο A (2003) *Looking for Spinoza: joy, sorrow, and the feeling brain*. Boston: Mariner Books
- Desmet P, Hekkert P, Jacobs JJ (2000) When a car makes you smile: development and application of an instrument to measure product emotions. *Adv Consum Res* 27:111–117
- Dodge R, Cline TS (1901) The angle velocity of eye movements. *Psychol Rev* 8:145–157. <https://doi.org/10.1037/h0076100>
- Ekman P, Friesen W (1978) Facial action coding system: a technique for the measurement of facial movement. Consulting Psychologists Press, Palo Alto
- Ekman P, Friesen W, Hager J (2002) *The facial action coding system*. Research Nexus, Salt Lake City
- Ekman P, Levenson RW, Friesen WV (1983) Autonomic nervous system activity distinguishes among emotions. *Science* 221:1208–1210. <https://doi.org/10.1126/science.6612338>
- Gambi E, Agostinelli A, Belli A, Burattini L, Cippitelli E, Fioretti S, Spinsante S (2017) Heart rate detection using microsoft kinect: validation and comparison to wearable devices. *Sensors* 17(8):E1776. <https://doi.org/10.3390/s17081776>
- Giorgetta C, Grecucci A, Bonini N, Coricelli G, Demarchi G, Braun C, Sanfey AG (2013) Waves of regret: a meg study of emotion and decision-making. *Neuropsychologia* 51(1):38–51. <https://doi.org/10.1016/j.neuropsychologia.2012.10.015>
- Goldberg J, Wichansky A (2003) Eye tracking in usability evaluation. In: Hyönä J, Radach R, Deubel H (Eds), *The mind’s eyes: cognitive and applied aspects of eye movements*. Oxford: Elsevier Science, pp 493–516
- Goleman D (1995) *Emotional intelligence*. Bantam Books, New York
- Haag A, Goronzy S, Schaich P, Williams J (2004) Emotion recognition using bio-sensors: first steps towards an automatic system. In: *Tutorial and research workshop on affective dialogue systems*. Springer, Berlin, Heidelberg, pp 36–48
- Hartridge H, Thompson LC (1948) Methods of investigating eye movements. *Br J Ophthalmol* 32:581–591. <https://doi.org/10.1136/bjo.32.9.581>
- Hui L, Ting LH, See SL, Chan PY (2015) Use of Electroglottograph (EGG) to find a relationship between pitch, emotion and personality. *Procedia Manufact* 3:1926–1931
- Izard CE (1979) *The maximally discriminative facial Movement Coding System (MAX)*. Instructional Resources Centre, University of Delaware, Newark, DL, Newark
- Javal E (1878) Essai sur la physiologie de la lecture. *Annales d’Oculistique* 82:242–253

- Johnston S, Linden DEJ, Healy D, Goebel R, Habes I, Boehm SG (2011) Upregulation of emotion areas through neurofeedback with a focus on positive mood. *Cogn Affect Behav Neurosci* 11(1):44–51. <https://doi.org/10.3758/s13415-010-0010-1>
- Josephson S, Holmes ME (2002) Visual attention to repeated Internet images: testing the scan path theory on the world wide web. In: *Proceedings of the eye tracking research & applications symposium 2002*. New York: ACM, pp 43–49
- Juslin P, Scherer K (2005) Vocal expression of affect. In: Harrigan J, Rosenthal R, Scherer K (eds) *The new handbook of methods in nonverbal behavior research*. Oxford University Press, New York, pp 65–135
- Kandel ER, Schwartz JH, Jessell TM, Siegelbaum SA, Hudspeth AJ (Eds) *Principles of neural science*. 5th. McGraw-Hill, 2013. ISBN 978-0- 07-181001-2
- Kim J, Bee N, Wagner J, André E (2004) Emote to win: affective interactions with a computer game agent. *GI Jahrestagung* 1:159–164
- Lang P (1995) The emotion probe: studies of motivation and attention. *Am Psychol* 50:372–385. <https://doi.org/10.1037/0003-066X.50.5.372>
- Lang P, Bradley M, Cuthbert B (1997) Motivated attention: affect, activation, and action. In: Lang P, Simons R, Balaban M (eds) *Attention and orienting: sensory and motivational processes*. Lawrence Erlbaum Associates, New Jersey, pp 97–135
- Lang P, Greenwald M, Bradley M, Hamm A (1993) Looking at pictures: affective, facial, visceral, and behavioral reactions. *Psychophysiology* 30:261–273. <https://doi.org/10.1111/j.1469-8986.1993.tb03352.x>
- Lera E De, Garreta-Domingo M (2007) Ten emotion heuristics: guidelines for assessing the user's affective dimension easily and cost-effectively 2(September):7–10
- Lewin K (1935) *A dynamic theory of personality*. McGraw-Hill, New York
- Levine EL, Xu X, Yang L-Q, Ispas D, Pitariu HD, Bian R, Ding D, Capotescu R, Che H, Musat S (2011) Cross-national explorations of the impact of affect at work using the state-trait emotion measure: a coordinated series of studies in the United States, China, and Romania. *Hum Perform* 24:405–442. <https://doi.org/10.1080/08959285.2011.614302>
- Loza D, Marcos S, Zalama E, Jaime G (2013) Application of the FACS in the design and construction of a mechatronic head with realistic appearance. *J Phys Agents* 7(1):31–38
- Martin DM, Teng JZ, Lo TY, Alonzo A, Goh T, Iacoviello BM, Loo CK (2018) Clinical pilot study of transcranial direct current stimulation combined with Cognitive Emotional Training for medication resistant depression. *J Affect Disord* 232:89–95. <https://doi.org/10.1016/j.jad.2018.02.021>
- Marrufo MV, Vaquero E, Cardoso MJ, Gomez CM (2001) Temporal evolution of α and β bands during visual spatial attention. *Cogn Brain Res* 12(2):315–320. [https://doi.org/10.1016/S0926-6410\(01\)00025-8](https://doi.org/10.1016/S0926-6410(01)00025-8)
- Mussakhoyayeva S, Kalidolda N, Sandygulova A (2017) Adaptive strategies for multi-party interactions with robots in public spaces. In: *International conference on social robotics*. Springer, Cham, pp 749–758
- Mutlu B, Yamaoka F, Kanda T, Ishiguro H, Hagita, N. (2009) Nonverbal leakage in robots: communication of intentions through seemingly unintentional behavior. In: *Proceedings of the 4th ACM/IEEE international conference on human robot interaction*, p 69. <https://doi.org/10.1145/1514095.1514110>
- Nishitani S, Shinohara K (2013) NIRS as a tool for assaying emotional function in the prefrontal cortex. *Front Hum Neurosci* 7:770. <https://doi.org/10.3389/fnhum.2013.00770>
- Norman D (2004) *Emotional design: why we love (or hate) everyday things*. Basic books, New York
- Notzon S, Steinberg C, Zwanzger P, Junghöfer M (2017) Modulating emotion perception—opposing effects of inhibitory and excitatory prefrontal cortex stimulation. *Biol Psychiatry Cogn Neurosci Neuroimaging* 3(4):329–336. <https://doi.org/10.1016/j.bpsc.2017.12.007>

- Phan KL, Wager T, Taylor SF, Liberzon I (2002) Functional neuroanatomy of emotion: a meta-analysis of emotion activation studies in PET and fMRI. *Neuroimage* 16(2):331–348. <https://doi.org/10.1006/nimg.2002.1087>
- Poole A, Ball L (2006) Eye tracking in HCI and usability research. In: Ghaoui C (ed) *Encyclopedia of human computer interaction*. Idea Group Reference, USA, pp 211–219
- Reeder RW, Pirolli P, Card SK (2001) WebEyeMapper and WebLogger: tools for analyzing eye tracking data collected in web-use studies. Extended abstracts of the conference on human factors in computing systems, CHI 2001. ACM Press, New York, pp 19–20
- Reuderink B, Mühl C, Poel M (2013) Valence, arousal and dominance in the EEG during game play. *Int J Auton Adapt Commun Syst* 6(1):45–62
- Ribeiro AS, Salvado D, Evans G, Augusto JS, Ferreira HA (2014) A multimodal low-cost platform for acquisition of electrophysiological signals interfacing with portable devices. In: *PhyCS*, pp 63–70
- Russel JA, Barret LF (1999) Core affect, prototypical emotional episodes, and other things called emotion: dissecting the elephant. *J Pers Soc Psychol* 76:805–819. <https://doi.org/10.1037/0022-3514.76.5.805>
- Scherer KR, Wallbott HG (1994) Evidence for universality and cultural variation of differential emotion response patterning. *J Pers Soc Psychol* 66:310–328
- Setz C, Schumm J, Lorenz C, Arnrich B, Tröster G (2009) Using ensemble classifier systems for handling missing data in emotion recognition from physiology: one step towards a practical system. In: 3rd international conference on affective computing and intelligent interaction and workshops, 2009. ACII 2009. IEEE, pp 1–8
- Spielberger CD (1988) *Manual for the State-Trait Anger Expression Inventory (STAXI)*. Psychological Assessment Resources, Odessa, FL
- Spielberger CD (1994) *State Trait Anger Expression Inventory (STAXI-2)*. OS Giunti, Firenze, Italy
- Stemmler G, Heldmann M, Pauls C, Scherer T (2001) Constraints for emotion specificity in fear and anger: the context counts. *Psychophysiology* 38:275–291
- Tracy J, Robins R (2004) Show your pride: evidence for a discrete emotion expression. *Psychol Sci* 15:194–197. <https://doi.org/10.1111/j.0956-7976.2004.01503008.x>
- Tutsoy O, Gongor F, Barkana DE, Kose H (2017) An emotion analysis algorithm and implementation to Nao humanoid robot. In: *The Eurasia proceedings of science, technology, engineering & mathematics*, vol 1, pp 316–330. Accessed from https://www.researchgate.net/profile/Fatma_Guengoer2/publication/320417231_AN_EMOTION_ANALYSIS_ALGORITHM_AND_IMPLEMENTATION_TO_NAO_HUMANOID_ROBOT/links/59e48102aca2724cbfe908e0/AN-EMOTION-ANALYSIS-ALGORITHM-AND-IMPLEMENTATION-TO-NAO-HUMANOID-ROBOT.pdf
- Watson D, Clark L, Tellegen A (1988) Development and validation of brief measures of positive and negative affect: the PANAS scales. *J Pers Soc Psychol* 54:1063–1070. <https://doi.org/10.1037/0022-3514.54.6.1063>

Hugo Alexandre Ferreira holds a medical degree from the Faculty of Medicine of the University of Lisbon (FMUL) and a degree in engineering physics from Instituto Superior Tecnico (IST) of the same university. He holds also a Ph.D. in Physics from IST, whereas his doctoral studies were in the field of nanotechnology, biosensors and biochips, microsystems and microfluidics. Additionally, he has a post-graduation in entrepreneurship and innovation management from Catolica Lisbon School of Business and Economics. He was founder and CEO of Haloris Nanotecnologias, a company that developed biosensors for in vitro diagnostics in the medical and agrifood fields. He was also a clinical education and applications specialist in computed tomography and magnetic resonance imaging at Siemens Healthcare and later he was a post-doc in neuroimaging at the Institute of Biophysics and Biomedical Engineering (IBEB) of the Faculty of Sciences of the University of Lisbon (FCUL). Presently, he is an assistant professor and coordinator of the

Integrated master's in Biomedical Engineering and Biophysics at FCUL. At IBEB, his fields of research include neurosciences, oncology, and digital health: by making use of medical images and signals, brain-computer interfaces and physiological computing wearables, he and his team are developing both clinical and non-clinical applications such as serious-games and neuromarketing. Recently, he has founded a number of companies in the biomedical field, including EmotAi, a company that developed a wearable and physiological computing platform for supporting user experience/user interface design and applications in various fields. Finally, he is also a consultant in Nanotech, Medtech and Life Sciences.

Magda Saraiva has a master's degree in Psychology of Justice and a Ph.D. in Basic Psychology from the University of Minho, Portugal. She is currently a postdoctoral researcher at Centro de Investigação e Intervenção Social (CIS), ISCTE-IUL, Lisbon, Portugal. Her main research topics are basic cognitive processes, in particular, human memory, emotions, and language. At CIS she conducts research about the production of false memories in collaborative memory tasks and on bilinguals. She is the main author and co-author of several scientific articles, published in peer-reviewed journals with high impact factor in the area of Psychology. In addition, she advises master's students' dissertations at ISCTE-IUL and is a reviewer in various international scientific journals in the area of Experimental Psychology.