Neuroscience Measurement Techniques
and Their Applicability to Consumer and Marketing Research

Neuroscience has developed a wide array of advanced measurement techniques that have been applied for decades in medical and academic contexts.

What are the major approaches, how do they differ from each other, and what are the pros and cons of each for use in consumer and marketing research?

The Big Picture

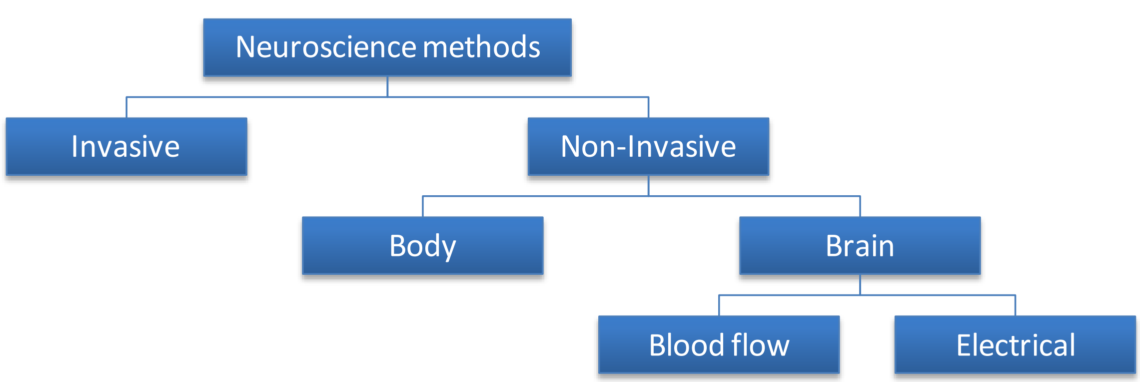
The first dividing line in the family of neuroscience techniques is ***invasive*** vs. ***non-invasive***. Invasive techniques are exactly what you would imagine – they involves taking measures inside the cranium. Invasive measures are only used in medical situations or in animal research. Obviously they not appropriate for consumer-oriented research.

Among the non-invasive techniques, the next level of differentiation is ***brain*** vs. ***body***. Brain methods measure or try to infer activity inside the brain. They are often called ***neuroimaging*** methods, because they involve creating pictures or images of activity within the brain itself (central nervous system). Body methods measure "peripheral" nervous system changes such as muscle movements, skin conductance, heart rate, respiration, and pupil dilatory response. Although body states are being measured, all of these responses are ultimately controlled by the brain.

Brain methods, finally, divide into two main categories: ***blood flow*** methods, which infer brain activity from localized increases in blood flow necessary to deliver more "energy" (oxygen and glucose) to neurons that are more "active", and ***electrical*** methods, which directly measure the electrical and magnetic signals produced when neurons are active.

Figure 1 is a graphic depiction of this neuroscience measurement "family tree":

Figure 1. Types of Neuroscience Measurement



Body measures

Although we often think of behavior in terms of overt movements such as walking, smiling, and speaking, the body also responds to internal and external stimulation in more covert ways – the skin sweats, the heart pumps harder, facial muscles contract microscopically, the eyes take in more light. These less overtly observable physiological measures play an especially important role in measuring unconscious or preconscious reactions to stimuli. They do this because they capitalize on the close connection between body and mind – our bodies often respond to environmental stimuli before our conscious minds have become aware that a response is taking place.

Some of the most relevant body measurement techniques that can be used in consumer and marketing research include:

Eye movement and tracking

Our eyes automatically track to what interests us, threatens us, or attracts us. Various changes in eye movements, including the speed of eye movement, duration of fixations, pattern and frequency of blinks, and patterns of searching behavior, are all relevant to how a person is responding to a stimulus like a picture or an advertisement. These movements can be measured and tracked within millimeters with sophisticated eye tracking hardware and software.

Pupilometry

This is the measurement of pupil dilation and contraction. Pupils dilate as a response to emotional arousal, attention, and cognitive load (i.e., the amount of information a person is thinking about). Pupil diameter changes are reliable and sensitive measures of emotional and cognitive reactions to stimuli in real time.

Facial Electromyography (EMG)

EMG measures the electrical activity generated by muscles. The muscles of the face are extremely responsive to emotional stimuli, including the corrugator or “frown” muscle and the zygomatic or “smile” muscle. Facial EMG can be used to rapidly detect emotional responses even before they are evident to the naked eye. Indeed, using EMG measures, it is possible to detect micro-expressions that occur automatically and unconsciously, before they are potentially masked by more voluntary “conscious” efforts to present a certain outward expression. EMG can thus be a highly sensitive measure of positive or negative valence (liking or disliking), especially of visual, auditory, olfactory (smell), and gustatory (taste) stimuli.

Electrodermal Activation (EDA)

EDA measures, such as galvanic skin response (GSR) or skin conductance response (SCR) measure the secretion from certain types of sweat glands that are prevalent on the hands and fingers. EDA measures are relatively easy to capture, reliable in single trial designs, and produce highly sensitive and stable measures of individual differences in psychological states and processes. Because greater skin conductance represents increased activation in the “flight or fight” system (sympathetic nervous system), SCR is an excellent measure of arousal or stimulation, but is generally not sensitive to the direction or valence of an emotional response. GSR is uses as a stress detector in the classic polygraph test.

Startle Reflex

Startle reflex is a robust indirect measure of both attention and emotional valence. While a person is engaged in some cognitive task (watching a video, viewing an image, reading a document) a short burst of white noise is intermittently presented through speakers or headphones. The person will respond to such unanticipated interruptions with eye blinking and muscle contraction, the classic components of the startle reflex.

Extensive research has shown that the magnitude of this startle reflex is proportional to attention and emotion. The less attention the person is paying to the stimulus, the smaller the startle reflex. The more emotionally negative the person perceives the stimulus to be, the larger the startle reflex. Startle reflex can be used to measure how interesting or engaging an ad or video is, and also the extent to which stimuli are activating negative or positive emotional reactions on a moment to moment basis.

Heart Rate

The beating speed of the heart can be an indicator of various physiological reactions, such as attention, arousal, and cognitive or physical effort. In psychophysiological research, heart rate is usually measured in terms of time between beats, and has been found to decelerate in the short-term when attention increases (deceleration is associated with an "orienting" response), and to accelerate in the long-term when experiencing negative emotional arousal (acceleration is associated with a "defensive" response).

Respiration

Respiration measures record how deep and fast a person is breathing. Measurement is captured by applying a strain gauge (like a rubber band) around the chest, or using components of heart rate measures. Fast and deep breathing can indicate excitement such as anger or fear, but sometimes also joy. Rapid shallow breathing can indicate tense anticipation including panic, fear or concentration. Slow and deep breathing indicates a relaxed resting state while slow and shallow breathing can indicate states of withdrawal, like depression or calm happiness.

Brain Measures

Brain measures, in contrast to body measures, focus on capturing the activity of the brain itself, either ***indirectly***, by measuring how brain activity affects blood flow, or ***directly***, by measuring the electrical or magnetic signals emitted as neurons communicate with each other.

Blood Flow Measures

There are two main measurement technologies used in neuroscience that derive images of brain activity by measuring blood flow in the brain: ***functional Magnetic Resonance Imaging*** (fMRI) and ***Positron Emission Tomography*** (PET). Both techniques provide indirect measures of brain activity because they rely on the assumption that mental activity increases demand for oxygen or glucose in regions in the brain that are activated, and that this need is met by increased blood flow to the region.

Positron Emission Tomography (PET)

PET involves the inhalation of a radioactive gas or the injection of a radioactive solution that is metabolized by various areas of the brain. Because of this requirement, PET is classified as an invasive technique by some observers. The greater the activity in a brain region, the more the radioactive tracer is present in that region, and the greater the PET signal at that location of the brain. Unlike other imaging techniques, which are used predominantly to measure neural activation, PET has been used to measure all aspects of the physiology of brain function including protein synthesis and activity at dopamine receptor sites.

Apart from an inherent limitation arising from the use of radioactive substances (governmental guidelines limit the total radiation dose per year per volunteer), the main technical limitation of PET technology is that the temporal resolution is relatively poor because it takes time before enough radioactive “ticks” can be counted. As a result, one can typically get only one picture per minute of brain activity and, as a result, PET produces only an averaged brain activity picture over that period. The spatial resolution of PET is quite good – down to one cubic centimeter – which is substantially better than EEG or MEG, but not as good as fMRI can yield.

Given issues surrounding handling and injecting radioactive isotopes to consumer volunteers, PET is not a technology that is likely to see much traction in consumer and marketing research. First, few research teams outside of academic or medical labs are qualified to administer PET scanning, and second, few volunteers are willing to be injected with radioactive substances to test consumer products.

Functional Magnetic Resonance Imaging (fMRI)
fMRI measures a signal called the Blood Oxygenation Level Dependent, or BOLD signal. This signal is derived on the physiological principle that blood delivered to a brain region is more oxygenated when the region is active, and thus, demanding more “energy” for sustaining that activity.

fMRI is currently the most popular neuroimaging technique for academic neuroscience research in healthy humans. It is beginning to be used in consumer research as well, but is limited in this usage because of its high cost and the limited availability of fMRI machinery. It uses powerful magnetic fields to alter the orientation of atoms in the brain and measures signals given off by these atoms as they return to their normal orientation.

Simply stated, brain areas that are active in performing a given task use more blood and, therefore, produce a stronger signal than other brain areas. The advantages of fMRI compared to PET are

(1) it does not require the use of radioactive substance, and
(2) it offers better spatial resolution (in the order of 1–5 mm.).

A limitation of fMRI is its temporal resolution – although much better than what is achievable with PET, it is poor when compared to EEG or MEG. Typically, the temporal resolution of fMRI is in the order of seconds (2–8 s) and is dependent on the strength of the magnetic field and the design of the experiment (e.g., in so-called event-related designs, the effects can be separated to the extent of about 1-2 s). Fundamentally, the temporal resolution of fMRI is limited by the underlying physiological blood flow response, since blood-flow to active brain areas occurs with a lag in the range of 6 s.

Another limitation is that fMRI is susceptible to erroneous results induced by subject movement. If the person in an fMRI scanner moves their head as little as 3 millimeters (about a tenth of an inch) the resulting image is effectively rendered meaningless. There are motion-detection and motion-correction algorithms that can be applied to the image data, but he algorithms work best if there is minimal motion to begin with. Because speaking causes head movement, verbal responses are essentially impossible to do in the scanner. Responses are limited to small movements of the fingers.

The need to restrict movement is one aspect of a broader issue with fMRI regarding comfort and naturalness. The technique requires that the subject lie supine and perfectly still inside a giant magnetic "donut" that emits a loud bang continually as the magnet charges and discharges. Even though subjects' heads are baffled with pillows, and noise cancellation headphones are often used, the noise cannot be entirely eliminated. This makes studies using auditory stimuli very difficult.

Some people find the experience claustrophobic, or at least highly arousing because of the noise and novelty. For consumer and marketing research, which is often focused on identifying subtle variations in emotional response to products, brands, ads, and messages, this can produce a confounding effect that is difficult to disentangle from responses to the stimuli themselves.

Recently there has been a bit of a backlash regarding fMRI research, particularly as it has been used in advertising and marketing domains, for an excessive focus on "localization" or attempting to define "hot spots" in the brain where activity occurs during various tasks or mental states. In response to a recent fMRI study appearing in the New York Times that purported to identify people's attitudes toward political candidates based on fMRI brain scans made while viewing pictures of candidates, a group of distinguished neuroscientists submitted a letter to the editor objecting to the reported findings, noting in part that:

> *… activity in the amygdala in response to viewing one candidate was argued to reflect "anxiety" about the candidate, whereas activity in other areas was argued to indicate "feeling connected." While such reasoning appears compelling on its face, it is scientifically unfounded.*
>
> *As cognitive neuroscientists who use the same brain imaging technology, we know that it is not possible to definitively determine whether a person is anxious or feeling connected simply by looking at activity in a particular brain region. This is so because brain regions are typically engaged by many mental states, and thus a one-to-one mapping between a brain region and a mental state is not possible. …*
>
> *As cognitive neuroscientists, we are very excited about the potential use of brain imaging techniques to better understand the psychology of political decisions. But we are distressed by the publication of research in the press that has not undergone peer review, and that uses flawed reasoning to draw unfounded conclusions about topics as important as the presidential election.*[1]

Given its limitations around cost, availability, and the physical restrictions imposed on subjects, fMRI is most applicable for academic studies and theory testing. It is less attractive as a substitute for

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[1] "Politics and the Brain," Letters to the Editor, *The New York Times*, November 14, 2007, signed by 17 neuroscientists. The letter referred to an Op-Ed piece, "This Is Your Brain on Politics," by Marco Iacoboni, Joshua Freedman and others, published November 11, 2007.

more qualitative or traditional market research approaches such as focus groups and survey questionnaires.

Electrical Measures

Electrical measures encompass techniques that record brain activity directly, through scalp-surface detection of electrical and magnetic signals emitted by the brain. Electrical signals are the literal mechanism through which the brain communicates and synchronizes activity across different anatomical regions. Electrical measurement techniques thus provide the most direct measures of cognitive processing, and are the only measures that record brain activity at the speed of cognition – that is, in milliseconds rather than seconds.

Electroencephalography (EEG)

The coherent activity of many thousands of neurons produces electrical potential differences across the scalp, which can be detected using an electrode cap connected to a high-quality signal amplifier. The machinery is only moderately expensive and readily available from multiple hardware vendors. EEG is a non-invasive and silent technology directly sensitive to neuronal activity. The time resolution of the EEG is only limited by the hardware, which, typically, can record a voltage every 1 to 3 milliseconds.

A subset of EEG measurement is the analysis of ***event-related potentials*** (ERPs). The major advantages of ERP methods lie in the high temporal resolutions they afford and their relatively low cost. ERPs have been studied for a long time in research on attention, emotion, memory, language processing, and other areas. They provide excellent avenues for studying consumer behavior.

For example, the P300 is a well-studied positive potential that occurs at about 300 ms in response to attention shifts and novelty. It can be used to precisely measure attentional shifts that may occur either overtly (accompanied by eye or body movement) or covertly (occurring "in the mind"). The N400 event-related potential is a very well established measure of semantic mismatch and expectancy violation. It is a negative potential that occurs after about 400 ms if two stimuli are incongruent either semantically or with beliefs. This ERP component can be used to measure brand associations – for example, brand attributes that fit poorly with a given brand name would yield a larger N400 component in the brain. Another well-known ERP component is the LLP or Late Positive Potential that occurs after 600 ms and that has been shown to be linked to emotional judgment and valence change.

Magnetoencephalography (MEG)

MEG is another electrical technique that is similar to EEG in that it is non-invasive, offers excellent temporal resolution (in the range of milliseconds), and can be used to measure neuronal activity continuously (a limitation of PET and fMRI).

Like EEG, MEG relies on the coherent activity of many neurons that, in addition to producing electrical signals, also produce magnetic fields that can be detected outside the head. The strength of these fields is extremely small, typically one part in one billion of the Earth's magnetic field. To date, the only instrument with the sensitivity required to record these fields is the superconducting quantum interference device (SQUID) coupled to a pick-up coil. The resultant, very expensive technology is known as magnetoencephalography (MEG). While MEG and EEG are conceptually similar technologies, MEG offers superior signal quality and very high time-resolution, but at a much greater cost.

In contrast to the blood flow methods, both EEG and MEG are limited in terms of three-dimensional spatial resolution because they can only measure signals outside the surface of the head. Any 3-dimensional localization of brain activity within the head has to be interpolated or modeled based on data collected at or just outside the scalp. The major differences between EEG and MEG have to do with cost and accessibility: MEG machines are much more expensive due to the fact that they require operations at near absolute-zero temperatures and are, therefore, much less readily available to researchers.

Rating the Alternatives: What Works Best for Neuroscience-Based Consumer and Marketing Research?

EEG, MEG, PET, fMRI, and body response measurement all require fairly complex techniques, specific expertise, and a somewhat longer time period for data acquisition than some traditional methods used in consumer and marketing research. They also differ from each other with respect to their advantages and disadvantages for research in this area. These pros and cons are summarized in Table 1.

In general, ***practicality*** and ***applicability*** are the major factors that determine the relative fit of these alternative measurement techniques to the research challenges of consumer and marketing research. Marketers and product developers need reliable results, delivered in a timeframe that matches their development and rollout cycles, that are cost effective, and that can provide actionable results.

Of the techniques reviewed here, body and brain-EEG measures match these requirements most closely. They can be especially effective when used together, enabling multiple measurements to be compared and "triangulated," thereby providing more reliable and replicable results.

The other approaches play large roles in academic research and have generated theoretical and practical insights that continue to drive and inform research across the neuroscience field. However, due to the limitations identified, they are not yet "ready for prime time" in the day-to-day world of consumer and market research.

Table 1. Pros and Cons of Neuroscience Techniques for Consumer and Marketing Research

Technique	Body	PET	fMRI	EEG	MEG
What is measured	Physiological responses	Changes in blood flow	Changes in blood flow	Electrical fluctuations	Magnetic fluctuations
Potential risks	None	Injection of radioactive tracer Potential claustrophobic reaction	Not compatible with ferromagnetic implants Potential claustrophobic reaction Noise	None	None
Temporal resolution	Determined by physiology	Low	Low	Very high	Very high
Spatial resolution	Not applicable	High	Very high	Low, better with more sensors	Low, better with more sensors
Equipment costs	Very inexpensive	Expensive	Expensive	Inexpensive	Expensive
Complexity of analysis	Moderate complexity	Relatively high complexity	Relatively high complexity	Moderate to high complexity depending on research design	Moderate to high complexity depending on research design
Applicability to consumer research	Very applicable	Low due to expense and injection requirement	Limited due to risks, cost, and naturalness issues	Very applicable	Limited due to cost and equipment complexity