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Meng-Hsien (Jenny) Lin, Samantha N.N. Cross, William J. Jones, Terry L. Childers,

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Meng-Hsien (Jenny) Lin
College of Business, California State University, Monterey Bay, Seaside, California, USA

Samantha N.N. Cross
Department of Marketing, Iowa State University, Ames, Iowa, USA

William J. Jones
Department of Marketing, University of South Dakota, Vermillion, South Dakota, USA, and

Terry L. Childers
Department of Marketing, Iowa State University, Ames, Iowa, USA

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Abstract

Purpose – This paper aims to review past papers focused on understanding consumer-related topics in marketing and related interdisciplinary fields to demonstrate the applications of electroencephalogram (EEG) in consumer neuroscience.

Design/methodology/approach – In addition to the review of papers using EEG to study consumer cognitive processes, the authors also discuss relevant decisions and considerations in conducting event-related potential (ERP) studies. Further, a framework proposed by Plassmann *et al.* (2015) was used to discuss the applications of EEG in marketing research from papers reviewed.

Findings – This paper successfully used Plassmann *et al.*'s (2015) framework to discuss five applications of neuroscience to marketing research. A review of growing EEG studies in the field of marketing and other interdisciplinary fields reveals the advantages and potential of using EEG in combination with other methods. This calls for more research using such methods.

Research limitations/implications – A technical overview of ERP-related terminology provides researchers with a background for understanding and reviewing ERP studies. A discussion of method-related considerations and decisions provides marketing researchers with an introduction to the method and refers readers to relevant literature.

Practical implications – The marketing industry has been quick to adopt cutting edge technology, including EEG, to understand and predict consumer behavior for the purpose of improving marketing practices. This paper connects the academic and practitioner spheres by presenting past and potential EEG research that can be translatable to the marketing industry.

Originality/value – The authors review past literature on the use of EEG to study consumer-related topics in marketing and interdisciplinary fields, to demonstrate its advantages over-traditional methods in studying consumer-relevant behaviors. To foster increasing use of EEG in consumer neuroscience research, the authors further provide technical and marketing-specific considerations for both academic and market researchers. This paper is one of the first to review past EEG papers and provide methodological background insights for marketing researchers.

Keywords Consumer neuroscience, Electroencephalogram (EEG), Event-related potential (ERP), fMRI vs EEG, Multi-methods

Paper type General review

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Consumer neuroscience is a growing approach to research that is garnering increased attention among academic researchers in the fields of marketing and consumer research. As marketing researchers increasingly acknowledge the shortcomings of self-reported data derived from surveys and qualitative methods, consumer researchers are searching for alternative (or complementary) methods to overcome the biases inherent in self-reports. Neuroscience methods provide one such alternative, as well as a means to dig deeper into understanding the cognitive processes and underlying mechanisms that help explain consumer behaviors. Kenning and Plassmann (2008, p. 532) note that the goal of consumer neuroscience "is to use insights and methods from neuroscience to enhance the understanding of consumer behavior". Yet, while gaining visibility over the past decade, this approach to consumer research is yet to gain widespread use as an effective and feasible methodological approach among marketing academics.

In contrast, a neuroscientific approach to understanding consumer behavior has increasingly been used by business practitioners, especially consumer brand managers. Major consumer product brands and companies, such as Coca-Cola and Campbell's, have ventured into the use of neuroscience methods, including functional magnetic resonance imaging (fMRI), eye tracking, electroencephalogram (EEG), magnetoencephalography (MEG) and other biometrics (i.e. physiological measures used to characterize human behavior) to better evaluate consumer responses to their ads (Looney, 2016). Other companies like General Electric (GE) have launched research centers, such as the GE BBQ research center, where researchers use EEG methods to study consumer responses to food and taste, to perfect their BBQ recipe (Garun, 2015). Associations such as The Neuromarketing Science & Business Association feature a list of neuromarketing companies across the globe, including big US-based consulting companies, such as A.C. Nielsen and the Forbes Consulting Group.

Within academia, the growing body of work in consumer neuroscience has footprints across many fields, with the major outlet still being neuroscience journals (see Solnais *et al.*, 2013 for a review of consumer neuroscience studies across specific fields). Other journal outlets include psychology, marketing and bioengineering. In marketing journals, EEG-based studies to date have most frequently been used in combination with brands and advertising stimuli. See Table I for an overview of marketing- or consumer-related EEG studies. A few studies have also used a related methodology, MEG, which is similar in its neurophysiological processes to EEG (Ambler *et al.*, 2004; Braeutigam *et al.*, 2001, 2004). Nevertheless, when marketing researchers have applied a neuroscientific approach to understanding the behavior of consumers, there seems to be a bias toward the use of fMRI (Reimann *et al.*, 2011; Plassmann *et al.*, 2015).

Irrespective of the specific neuroscience approach, Plassmann *et al.* (2015) proposed five ways neuroscience can be applied to improve academic and practitioner understanding of marketing theories and consumer behavior:

(1) identifying mechanisms;

(2) measuring implicit processes;

(3) dissociating between psychological processes;

(4) understanding individual differences; and

(5) improving predictions of behaviors.

All of the EEG studies reviewed in Table I focus on at least one of the five areas of application to marketing proposed by Plassmann *et al.* (2015), with No. 5, predicting consumer behaviors, being the most common application of the EEG approach.

Table I. Summary of marketing papers using EEG

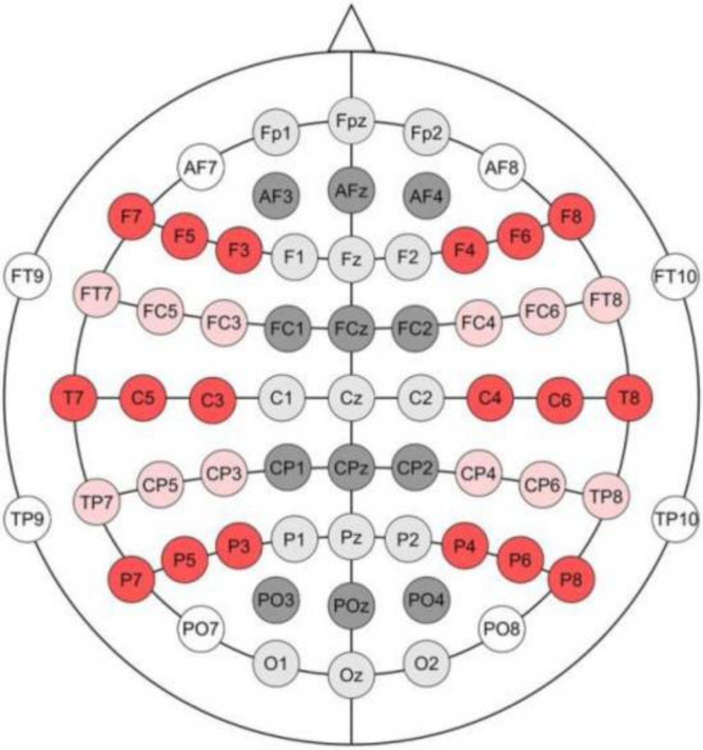
Author	Year	Journal	Stimuli and marketing substance	Methods	EEG waves or ERP component
Ambler *et al.*	2004	*Psychology & Marketing*	Brands and product	MEG	magnetic field activity
Barnett and Cerf	2017	*Journal of Consumer Research*	Movie trailer	EEG (and GSR, HR, respiratory rate)	alpha oscillation (cross-brain correlations)
Braeutigam *et al.*	2001	*Neural Plasticity*	Brands and product	MEG	magnetic field activity
Braeutigam *et al.*	2004	*European Journal of Neuroscience*	Brands and product	MEG	magnetic field activity
Boksem and Smidts	2015	*Journal of Marketing Research*	Ads (movie trailers)	EEG	beta and gamma oscillations
Chen *et al.*	2009	*Cyber Psychology and Behavior*	Online book reviews	ERP	LPP (prolonged P300)
Cook *et al.*	2011	*Journal of Neuroscience, Psychology and Economics*	Print ads	EEG	delta and beta-3; source locolization (LORETA)
Daugherty *et al.*	2016	*Journal of Business Research*	TV ads	dense-array EEG	3 epochs: 200-350, 350-500, 500-800
Guo *et al.*	2016	*Journal of Neuroscience, Psychology and Economics*	eWOM (online recommendations)	ERP	N200, P300
Jin *et al.*	2015	*NeuroReport*	Brands	ERP	N400
Jones *et al.*	2012	*Biological Psychology*	Price	ERP	FN400, LPC, P200
Khushaba *et al.*	2013	*Expert Systems with Applications*	Product	EEG	alpha, beta, theta, gamma, delta
Lin *et al.*	2016	working paper (marketing)	Scent	ERP	LPP
Ma *et al.*	2007	*NeuroReport*	Brands	ERP	N270
Ma *et al.*	2008	*NeuroLetters*	Brands and product	ERP	P300
Ma *et al.*	2010	*NeuroLetters*	Brands and images	ERP	N200, P300
Ohme *et al.*	2010	*Journal of Economics Psychology*	TV ads	EEG	alpha band frontal assymetry
Ohme *et al.*	2009	*Journal of Neuroscience, Psychology and Economics*	TV ads	EEG (and EMG, GSR)	alpha (emotional response)
Pohzaharliev *et al.*	2015	*Journal of Marketing Research*	Brands	ERP	P2, P3, LPP
Schaefer *et al.*	2016	*Plos1*	Price	ERP	FRN (feedback related negativity); P300
Telpaz, Webb and Levy	2015	*Journal of Marketing Research*	Product	EEG(ERSP)/ERP	theta/N200, FRN
Vecchiato *et al.*	2010	*Brain Topography*	TV ads	EEG (and GSR, HR)	theta and gamma
Vecchiato *et al.*	2011	*Medical and Biological Engineering and Computing*	TV ads	EEG	theta and alpha (power spectral density)
Venkatraman *et al.*	2015	*Journal of Marketing Research*	TV ad	EEG (and fMRI, eye-tracking, implicit attitude test)	alpha wave (occipital alpha and frontal assymetry)
Wang and Han	2014	*NeuroReport*	Product	ERP	P300
Wang, Ma and Wang	2012	*NeuroLetters*	Brand names	ERP	N400
Young	2002	*Journal of Advertising Research*	TV ads	EEG	Engagement Index = beta/(alpha + theta)

One of the main goals of this paper is to foster wider application of the EEG approach in consumer research. By providing an introduction to EEG technology and reviewing past EEG studies related to marketing, we hope to provide initial background information on this topic for researchers that may be interested in using this method. Using Plassmann *et al.*'s (2015) proposal as a framework to better understand the application of EEG-based methods to advance consumer research, we provide specific EEG examples for each of Plassmann *et al.*'s (2015) five proposed applications of neuroscience methods. The paper advocates the potential application and contribution of an event-related potential (ERP) approach (a specific EEG technique that uses time-locked EEG activity, which are brainwave responses triggered by stimuli, to help capture neural activity related to both sensory and cognitive processes). An overview of commonly studied cognitive and emotional processes in consumer research is provided, with corresponding EEG waves and ERP components, to explain the processes. Considerations and decisions involved in conducting an ERP study in consumer research (with limited technical details) are also outlined and further discussed. We conclude by comparing the advantages of using EEG methods over the more commonly used fMRI for marketing and consumer research, and use examples of two current fMRI studies to demonstrate how these may be translated into ERP studies. These examples show how such a triangulation design could potentially enhance the findings and allow another perspective on the data.

Understanding electroencephalogram activity and event-related potential components

EEG is essentially a measure of brainwave activity detected at the surface of the scalp. To understand why certain study design procedures are necessary and how technical decisions are crucial for increasing the quality of the data for inferences to be made, we need to first understand the physiology of the brain. The basic building block of the brain (and nervous system) is the neuron. Neurons communicate with each other electrochemically (i.e. via tiny electrical signals). When neurons are similarly aligned, as is the case for the neocortex or outer layer of the brain, the electrical activity can be measured at the scalp with electrodes using a differential amplifier (which will be discussed in more detail in later sections). By way of analogy, this is like a chorus. Many singers (neurons) on a stage, all aimed at an audience, can produce a powerful sound (even louder when microphones and amplifiers are in place). As a direct measure of brain-related activity, EEG can thus be used to understand how brain cells (neurons) communicate with each other (sing together). EEG is thus distinct from fMRI, which is a measure of changes in blood flow to a brain region reflecting neural operations within that area.

The use of EEG methods, which is almost real-time data, can assist researchers in discerning cause and effect relationships between the marketing stimuli and their associated cognitive response. These responses are typically revealed through one or more ERP components or EEG neural oscillations (also called "waves" or "bands"). ERPs are one specific application of the EEG method, where a large number of trials are "time-locked" to understand perceptual or cognitive processes in response to sensory stimuli. In other words, the onset of the stimulus is set as a zero time-point, and the brain activity (waves), in response to the stimuli, is recorded. These brainwaves are detected at the surface of the scalp through electrodes (sewn onto a cap) located at specific areas of the scalp (see Figure 1 for the distribution of these electrodes). Further amplification of the electrical brain activity is important because ERP signals are small ($<10\ \mu V$), in part due to obstruction (also known as occlusion) by the skull and other impediments. To continue our earlier analogy, think of putting the chorus or just one singer behind a wall. Amplification helps boost the



Notes: A: anterior; C: central; F: frontal; Fp: Frontal parietal; O: occipital; P: parietal; z: scalp midline electrodes; Even numbers (2-10): right hemisphere, numbers increase from midline z; Odd numbers (1-9): left hemisphere, numbers increase from midline z

Figure 1. Distribution of electrodes based on the international 10-20 system

tiny sound you might hear on the other side of the wall, much like if you put a drinking glass to your ear and the glass to the wall.

Background material for understanding ERP methods is next briefly introduced to assist readers who are unfamiliar with EEG technology. This section describes the naming system that is used to quantify and discuss ERP data, followed by an overview of the different categories of ERP components. However, this paper is not meant to provide an exhaustive guideline to understand ERP methods. Those interested should refer to Handy (2004) and Luck (2014) for more in-depth understanding of conducting ERP research.

Quantifying event-related potential

Nomenclature is crucial for understanding ERP components and also its distribution on the scalp. The electrode labeling system, such as Pz, C4, O3, derives from the 10/20 system (Jasper, 1958) – a system for naming electrodes based on their scalp-related location (geography). A word of caution is that activity detected at a particular scalp region does not necessary imply it directly originated from the brain region underneath, as the electrical activity detected at the scalp is a summate of brain activity. Returning to our chorus analogy, consider if a group of sopranos standing at the far-left side of the choir powerfully projected their voices toward the right (their left). On the other side of the wall with your drinking glass placed on the right side, you might hear the sopranos' *summated* sound more robustly than the other singers and conclude they are relatively adjacent to you, when they are not. Figure 1 provides a visual of the international 10/20 system. For example, Pz means that the electrode is placed over the scalp in an area roughly subtended by parietal tissue. Labels F, T and O correspond to frontal, temporal and occipital cortices, respectively, whereas C denotes central scalp. Use of Z denotes scalp midline, whereas odd (even) numbers indicate left (right) hemisphere electrodes.

One of the most meaningful aspects of the ERP-imaging approach is components, which are characteristic features of ERP waves linked to sensory and psychological processes. The two most important measures of components are amplitude (as noted earlier) and latency. The former is often quantified in microvolts (μV) and the latter in milliseconds (ms). A typical ERP waveform is depicted in Figure 3. To reinvoke our chorus analogy, let us have the chorus sing Handel's Hallelujah Chorus. The opening words are broken up as Hal – le – lu – ja! Each of the notes are like separate ERPs. The latency comparison to ERP is obvious – e.g. ja comes after Hal. (In theory, this could be measured in milliseconds, but it would upend musical tradition.) All of these notes are sung *forte*, meaning loudly, which is comparable to ERP amplitude (and again amplitude could be used with music). Readers are cautioned that when embarking on understanding ERP components, variations in ERP labeling do occur. Some "camps" consider positive (P) and negative (N) deflections, which are reflected in the direction of the deviation from the baseline, in the ERP average such as the third positive deflection or "P3". (Music actually has something similar when you consider differences between the Treble and Bass scales. We will not speculate which is more negative.) Others consider only positive deflections peaking at around 300 ms post stimulus onset to be so and would use the term P300. (In music some notes are "tied" outside their measure. That's a close-ish analogy, but nitpicky either way.)

Certain ERP components can be used as indices to observe changes in response to stimuli to reflect cognitive processes taking place. Table II provides a summary of commonly studied ERP components and the corresponding cognitive processes they infer. A note of caution when interpreting ERP components is to avoid overgeneralization of their meaning. Subtle differences in time windows and scalp distributions may be due to task contingencies, but not fundamentally different processes. This functional view is similar to careful fMRI studies that avoid broad generalizations regarding neural regions and behavioral specificity (e.g. the amygdalae and fear). (If a flamboyant conductor holds the first Hal for a bit longer for a lively audience, this does not change the fact that it is the first sung note of the piece.) Although, and also like fMRI, there do seem to be components with a high degree of specificity for a behavior. For example, a response-locked ERP component called the error-related negativity (ERN) generally peaks over the anterior scalp within 200 ms of a subject making a conscious error.

In another example, the component late positive potential (LPP) is thought to be functionally similar to P3b and so is related to processes of memory updating and emotional processing according to Polich (1997), but later. (Much like how the *second* "Ha" in the Hallelujah Chorus is like the first, but comes later.) Like P3b, LPP is distributed posteriorly; thus, Pz can be used as the electrode of interest because LPP is maximal over this area of the scalp at around 600 ms. (As if the tenors, situated similarly, were chosen to emphasize a part of the score previously emphasized by the sopranos.) To determine this, data can be carefully examined at channels across the scalp when attempting to verify a known

Category	When observed	Functional significance
Pre-stimulus		
Contingent negative variation (CNV)/ Bereitschaftspotential (BP)	In anticipation of a stimulus when a (motor) response is required. Usually triggered by a warning stimulus. See Tecce (1972) for a review	Sensitive to attention. Larger for cognitively complex tasks and when a motor response is given
Stimulus preceding negativity (SPN) - non-motor aspect of CNV	In anticipation of motivational stimuli or knowledge of results (KOR)	Affective anticipation (Böcker *et al.*, 2001). Ohgami *et al.* (2006) found that SPN over left hemisphere sites is larger under reward (possibly because of positive emotion)
Obligatory\exogenous		
P100(P1)/N100(N1)	Sensory-obligatory components (i.e., *will* happen) to sensory stimuli. See Näätänen and Picton (1986) for a review	Sensory processing. Modulated by motivational salience, attention and relevance (Luck, 2005a, 2005b; Ibanez *et al.*, 2012)
P200(P2)	A sensory-obligatory component (with subcomponents). Studied in language, selective attention (e.g. threat), working memory and other paradigms	Represents the end response of the brain to the *stimulus* itself, and is involved in selective attention (Kotchoubey, 2006). Could be the earliest component to respond to affective valence (Delplanque *et al.*, 2004) P2 to prices without promotions is larger when High MA consumers make a "buy" decision (Jones *et al.*, 2012)
N200 (N2) "family"	Classically via oddball experiments and no-go tasks. A subcomponent, N2c, is elicited by classification tasks. Several subcomponents are subtended by diverse scalp topographies (Folstein and Van Petten, 2008). See Näätänen and Picton (1986) for a review	Deviation behavior (e.g., observing oddballs). Response inhibition. Cognitive control. In marketing, increased amplitude associated with unfamiliar brands (Ma *et al.*, 2010) Subcomponents, most notably N2b and N2c, are attention dependent (Näätänen and Picton, 1986)
Long latency\endogenous		
P300 (P3) "family"	Generally elicited during "target" processing. P3 is an "endogenous" component as it relates to *internal* decision-making more so than external stimulus properties. A frontal P3 or P3a is sometim es contrasted with a parietal P3b. (See Polich, 2007 for a model.) Decreased P3a latency for brand logos has been found after watching interactive vs noninteractive ads (Treleaven-Hassard *et al.*, 2010)	Probably the most widely studied ERP. Originally thought to represent context updating (Donchin and Coles, 1988). Broad properties now ascribed to P3 include resource allocation of attention and memory processes (Polich, 2007) P3 may reflect propensity to buy (Guo *et al.*, 2016; Jones *et al.*, 2012)

(*continued*)

Table II. Summary of ERP components

Category	When observed	Functional significance
N400(N4)	Elicited via incongruity experiments such as semantic anomalies. Kutas and Federmeier (2011) produced an outstanding review covering 30 years of N4(00) research	Although thought of as a "language component", other incongruities can elicit N4 such as brand name-product incongruities - e.g. Pepsi shoes (Wang *et al.*, 2012)
LPP	Similar to and overlapping with P3, LPP is frequently observed for affective perception tasks such as those employing the International Affective Picture System (IAPS)	Hajcak *et al.* (2010) argue that "the amplitude of the LPP is determined by: willful modulation of emotions, reappraisal instructions, preceding descriptions, the way in which stimuli are initially appraised, and manipulations of attention", and contend that its time course could be used to "quantify emotional reactivity and regulation" (p. 147)
Sustained slow waves		
Positive and negative slow waves (PSW and NSW)	Tasks involving cognitive effort such as math computations. Emotional stimuli have also been shown to elicit slow waves	Similar to CNV, however these ERPs are observed long after the presentation of a stimulus. Slow waves can be conceived of as indexing further task-invoked activity beyond the time window of earlier ERPs (Ruchkin, *et al.*, 1988). While the amplitude of slow waves might be an indicator of resource allocation, different patterns in slow wave topography could indicate differences in neural regions brought to bear on a task (Rösler *et al.*, 1997)

Table II.

distribution (Figure 2). As the latter rows of Figure 2, ERP effects during this time window are thought to be derived from internal information processing and are sometimes referred to as endogenous components. This contrasts with components in earlier time windows such as N100. Sometimes called exogenous components, ERPs like N100 are thought to be compulsory and driven by sensory-related processes. See Table II for more examples and details of endogenous and exogenous ERP components.

Another class of ERP, called slow waves or slow-cortical potentials, is sensitive to cognitive load and increasing task demands among other cognitive operations, and have very low frequencies. See Table II for examples such as positive and negative slow waves. These late window ERPs do not exhibit well-defined amplitudes and latencies; however, research increasingly points to a tight coupling of slow waves and the fMRI blood-oxygen level-dependent (BOLD) signal (Khader *et al.*, 2008). We think these types of components offer many research possibilities, including cross-validating an experimental paradigm previously used with fMRI, which is discussed later in this paper.

Slow wave studies generally make use of mean amplitudes over large time windows. This is because slow waves lack characteristic shapes for using peak amplitudes as dependent variables of interest. Conceptually, these components are like the last minute of radio songs. From an audience perspective, "hanging on" is less about one's favorite "moment" of a song and more about the ongoing enjoyment until it ends. In many cases, mean amplitudes and area

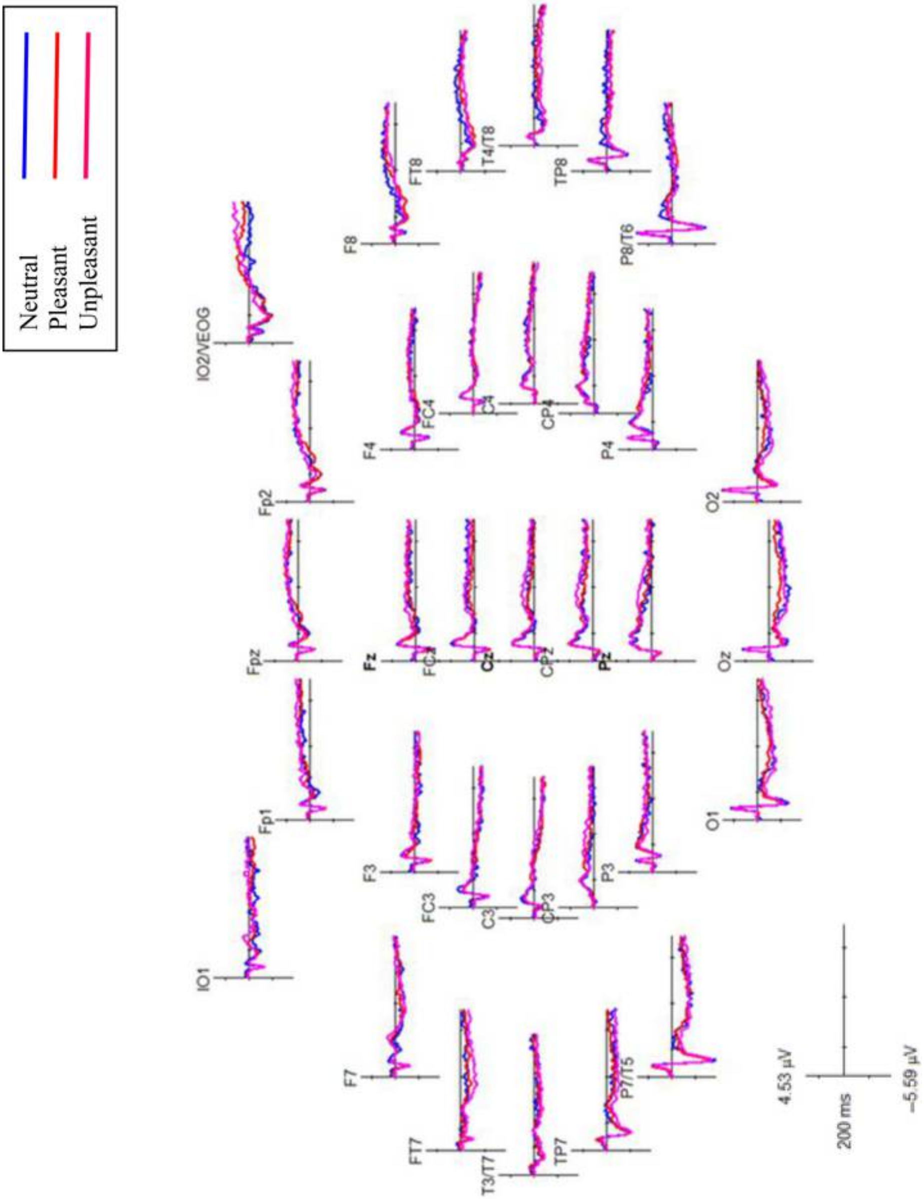


Figure 2.
Grand averages to verify LPP scalp distribution

measures are preferred to their peak counterparts – i.e. the point and time at which a component reaches its maximum amplitudes. Although once common, peak latency is susceptible to latency variability (Luck, 2005a, 2005b). Peak amplitude is often biased when due to differences in noise levels between groups (Luck, 2014). For example, children are more prone to artifacts; therefore, their ERPs are frequently composed of fewer trials.

Advantages of an electroencephalogram approach to consumer research

Compared to other methods, EEG is a relatively less invasive and less expensive method of measuring brain waves on the surface of the scalp, which is increasingly gaining attention in the field of marketing research. EEG is especially useful for capturing direct and objective data to further assist researchers in understanding the cognitive and emotional processes involved in information processing and decision-making. We use Plassmann *et al.*'s (2015) framework, which describes five general marketing applications of neuroscience research, to demonstrate and discuss the application of these guidelines, specifically to EEG studies in marketing. We also discuss a few marketing-related MEG studies, where applicable, given the similarities to EEG. Furthermore, this framework, combined with corresponding study examples, provides readers with an overview of the functional benefits of considering EEG as an alternative or complementary approach to conducting consumer research.

Identifying mechanisms

Understanding the underlying cognitive and emotional mechanisms allows consumer researchers to better explain and predict consumer decision-making and behaviors. In a study on brand extensions, the use of ERP methods helped identify how consumers recognize branding information based on categorization processes (Ma *et al.*, 2010; Wang *et al.*, 2012). In their research, Wang *et al.* (2012) used tasks that paired brand name with product category. Furthermore, they found that participants' strong associations with famous brand names triggered enhanced amplification of N400, signaling processing of familiar information, and further increased the preference of the extended brand name (Wang *et al.*, 2012). In another study, Ma *et al.* (2010) demonstrated that emotions were found to have an impact on brand extension preferences but only for certain product categories, such as clothing, and is modulated by negative emotions. These underlying mechanisms were reflected in an enhanced N200 when a new (unfamiliar) brand was introduced.

Moreover, in an investigation on purchase behaviors for luxury goods, Pozharliev *et al.* (2015) discovered the role of emotions in influencing purchase decisions, especially during the presence of others, as reflected in an enhanced LPP. Because of the almost real-time characteristics of EEG, which was sensitive enough to capture fleeting emotions, Lin *et al.* (2016) were also able to demonstrate the relationship between scent and emotions through an enhanced LPP. This relationship was not shown consistently with traditional survey methods in past research. Chen *et al.* (2009) also focused on the LPP component to explore online purchase behaviors in the context of book sales by considering the consistency (vs inconsistency) of the online recommendations. They explained this online herding behavior as the underlying mechanism driving the increased online purchase when recommendations were consistent. Again, this finding was reflected in an enhanced LPP.

Measuring implicit processes

Implicit processes are often difficult to measure when using self-report measures such as surveys. Furthermore, the validity of the process measured through these methods is often questioned. Reaction time garnered through neuroscientific methods have an advantage when it comes to capturing implicit processes. Such processes include social influences on purchase decisions and behaviors, stemming from conformity to social facilitation (Pozharliev *et al.*, 2015), reflected in an increased P300, and other implicit emotional processes, which are reflected in the LPP component. Chen *et al.* (2009), as evidenced by an enhanced prolonged P300, physiologically demonstrated herding behavior observed in online purchases based on consistent book recommendations. An enhanced N200 associated with familiar sources (vs unfamiliar sources), also verified the role of trust in online book recommendations (Guo *et al.*, 2016).

Jones *et al.*'s (2012) study focused on understanding consumer processing of pricing and discount information. They found that the P300 was enhanced in high math anxiety individuals; a finding which suggested high emotional and motivational processes were involved during these pricing and discount-related tasks. Other implicit cognitive processes, such as working memory, were detected in a dense array EEG study measuring the effectiveness of a direct marketing TV ad (Daugherty *et al.*, 2016). In a multi-method study, the detection of affective and attentional processes was measured via the alpha wave (Venkatraman *et al.*, 2015). To understand the effects of scent valence on eliciting emotions, Lin *et al.* (2016) were able to show a negativity bias, where unpleasant scents induced stronger emotional effects, reflected in higher LPP amplitudes, in comparison with pleasant scents.

Braeutigam *et al.* (2004) conducted an MEG study which focused on understanding decision-making processes involving memory retrieval. Gender differences were revealed. Specifically, category-specific strategies were used in women, whereas spatial memory is relied on for virtual shopping tasks in men. In another study, Braeutigam *et al.* (2001) used the temporal advantages that MEG provides to dissect the decision-making process by identifying key neural correlates that occur across four stages starting from the visual cortices (after 90 ms), followed by temporal (325 ms), frontal (510 ms) and parietal (885 ms). Results showed that visual processes at the early stages and memory processes at the later stages are involved in purchase decision-making in a virtual grocery shopping setting. Although these effects are not EEG specifically, we mention them here to elucidate the comparative nature of methods. Lin *et al.* (2016) find an LPP effect comparable to the parietal effect observed by Braeutigam *et al.* (2001).

Dissociation of processes

As an example of dissociation of processes, Lin *et al.* (2016) investigate the relationship between scent and emotions and consider the modulating role of individual differences in sense of smell in this relationship. The authors investigate the regulation of this scent-emotion relationship through two systems, emotion (hot) vs cognitive (cold), via a corresponding scent detection vs scent identification smell task. Results revealed an interaction effect between individual differences in olfactory sensitivity and task on LPP amplitude. More specifically, an emotional response was elicited as reflected in an enhanced LPP during the detection task. Whereas in the identification task (discerning the scent involves additional cognitive resources), individuals with heightened sensitivity to smell display an automatic protective mechanism. As a result, emotional responses are attenuated hence LPP is decreased. Taken together, we believe EEG provides much potential application in this area and is worth further exploration.

Understanding individual differences

While individual differences have been studied through the use of scales to differentiate responses among the population, the use of neuroscience methods can further demonstrate differential responses in brain activity. Jones *et al.* (2012) investigated the role of math anxiety and gender in processing pricing and discount information. The authors found that FN400, which reflects conceptual fluency, differs between high (vs low) math anxiety individuals. In the same study, the late positive component concurrently differs between consumer groups, which reflects varying retrieval processes (Jones *et al.*, 2012).

In an investigation on individual differences in olfactory sensitivity, Lin *et al.* (2016) found that emotional processes differ between individuals who have a high sensitivity to smell (vs a normal sense of smell). Olfactory-sensitive individuals reveal an automatic suppression of emotions, reflected in an attenuated LPP, when in contact with scents.

Braeutigam *et al.* (2004) also used an MEG study to examine gender differences in a virtual grocery-shopping task. Their findings revealed different cortices were activated for each gender which suggested different decision-making processes were used.

Improving predictions of behavior

Many papers focus on the predictive characteristics of neuroscience measures to assist marketers in predicting consumer behavior. Beta and gamma oscillations during the viewing of movie trailers have been discovered to predict box office sales (Boksem and Smidts, 2015). In a more recent EEG study, also conducted in the movie theater, the authors used alpha oscillations to calculate neural similarity to predict free recall and movie ticket sales (Barnett and Cerf, 2017). The success of brand extensions has been studied by using conflicting brand names (vs those with no conflict) to demonstrate a differentiated N270 (Ma *et al.*, 2007) for future diagnostic purposes. Another useful ERP component, N400, was found to capture familiarity in predicting success in brand extensions (Jin *et al.*, 2015). In their study, Jin *et al.* (2015) discovered that strong associations with famous brand names were reflected in an increased N400, predicting higher preferences.

Similarly, preferences for extended brand names have been reported to be reflected in larger P300 amplitudes (Ma *et al.*, 2007, 2008). Wang and Han (2014) used the P300 as an indicator of preferences for particular product attributes. Furthermore, buying decisions were predicted by P300 based on pricing expectations of individuals (Schaefer *et al.*, 2016). Telpaz, Webb and Levy (2015) used a combination of EEG and ERP measurements to predict product preferences, including the theta wave, N200 and FNR. Also related to understanding product preferences, Khushaba *et al.* (2013) studied the relative importance of different product (e.g. cracker) attributes involved in the decision-making process, by capturing cognitive processing reflected in EEG waves such as alpha, beta and theta.

In other attempts to predict the success of advertisements, one of the earliest EEG studies in advertising calculated an engagement index using beta, alpha and theta measurements (Young, 2002). To predict the effectiveness of direct TV marketing ads, Daugherty *et al.* (2016) used an inductive research approach to compare three successful (vs three unsuccessful) ads using dense-array EEG data.

Understandably, each paper may cover one or more of Plassmann *et al.*'s (2015) stated applications. For example, in Lin *et al.* (2016), four of the five applications were relevant in their study on understanding the role of individual differences in the relationship between scent and emotions:

(1) identifying mechanisms (such as the role of emotions in the processing of scent);

(2) measuring implicit processes (such as the observed automatic attenuation of emotions and negativity bias in scent valence);

(3) dissociating between psychological processes (such as differentiating the relationship between cognitive and emotional processes under varying levels of activity); and

(4) understanding individual differences (such as olfactory sensitivity).

The following section reviews EEG (and ERP) studies in consumer neuroscience. We further categorize these studies into the substantive areas and discuss the corresponding EEG waves or ERP components captured to understand the underlying cognitive or affective processes.

An overview of marketing-related electroencephalogram studies

Many EEG studies focus on cognitive and emotional processing in participants in response to a particular stimulus. From the selected EEG/ERP studies reviewed (Table I), whether it is processing ads or brands, products or price, the researchers all attempt to understand one or more of the following relevant cognitive processes in consumer research:

- attention and memory;
- attitudes and preferences;
- information-based decision-making; and
- affect and emotions.

This section will briefly reflect on marketing-related EEG studies focusing on these four cognitive processes and highlight and explain the relevant ERP components or EEG waves. This discussion will provide readers with an initial understanding of EEG applications in consumer research.

Attention and memory

Cognitive processes related to attention and memory are typically revealed through the following components: alpha wave, P100 and N400. Alpha band oscillations (8-12 Hz), which are regular cyclic voltage changes originating from the occipital lobe (located near the occipital bone at the back of the head), have been widely associated with the cognitive processing of attention (Klimesch, 2012), where attention increases when the alpha wave decreases. Venkatraman *et al.*'s (2015) study demonstrated that the occipital alpha wave is an indicator of enhanced allocation of attentional resources in response to ad stimuli. Similarly, an early sensory-specific ERP component, P100 onset, can reflect visual attention and is often captured in the occipital electrodes on the scalp (Woodman, 2010). In their study on movie trailers, Barnett and Cerf (2017) demonstrated that alpha oscillations will enhance later recall. The authors used alpha oscillations to calculate neural similarity, via the process of using movie trailers to synchronize different moviegoers' brain activity, to further show the predictability of alpha oscillation on movie recall.

Another component, the N400, is known to be associated with meaningful information, and hence represents access to the semantic memory (Kutas and Federmeier, 2000; Kutas and Federmeier, 2011). In the study of memory processes, one signal of familiarity is reflected in the decrease of the N400 component. For example, when a familiar or famous brand was presented, categorization processes are triggered, as reflected in the N400, which in turn led to a preference for the brand name (Jin *et al.*, 2015; Wang *et al.*, 2012). Refer to Table II for additional descriptions of P100 and N400.

Attitudes and preferences

For cognitive processes related to attitudes and preferences, the N200 and P300 components, and theta and beta waves have been studied in marketing-related topics. In a study on extended branding and product category, the N200 component, was enhanced when encountering a new clothing brand, especially under the influence of primed negative emotions (Ma *et al.*, 2010). This finding suggested that both emotions and product category played a role in the perception of brand extensions. The P300 component was also shown to be a predictor of preferences for product attributes (Wang and Han, 2014), where an enhanced P300 was detected after viewing a preferred product. See Table II for additional descriptions of N200 and P300.

In their EEG study, Telpaz *et al.* (2015) also found that a smaller N200, reflecting their value-related cognitive mechanisms (Folstein and Van Petten, 2008), and a weaker theta band (5-8 Hz), which reflect related losses and negative outcomes, indicated preferences for goods. Larger beta waves (12-30 Hz), which are associated with reward processes, were detected during the viewing of movie trailers in another EEG study, and predicted higher preferences for the movie (Boksem and Smidts, 2015).

Information-based decision-making

Again, the N200 and P300 components are typically activated for cognitive processes related to information-based decision-making (Table II). According to Patel and Azzam (2005), the N200 and P300 are often studied together in the Go/NoGo paradigm. Guo *et al.* (2016) studied the influence of online familiar (vs unfamiliar) recommendation sources. They found that the N200 component was enhanced during unfamiliar recommendation sources, whereas the P300 component was the largest during familiar recommendations. The authors concluded that the N200 can be applied in a decision-making task where the N200 component reflects processing of information, and the P300 component predicts propensity to buy. They further inferred that familiarity is associated with trust (Guo *et al.*, 2016). In other studies, researchers analyzing pricing expectations found that an enhanced P300 resulted in later purchasing behavior (Schaefer *et al.*, 2016) and was also a predictor of the successfulness of brand extensions (Ma *et al.*, 2007, 2008).

Affect and emotions

Cognitive processes related to affect and memory are typically revealed through the following components: alpha wave and LPP component. The frontal alpha wave has been used to indicate the affective responses to TV ads, as reflected in hemispheric alpha wave asymmetry (Ohme *et al.*, 2009; Ohme *et al.*, 2010; Venkatraman *et al.*, 2015). In Pozharliev *et al.*'s (2015) ERP study, the LPP component, reflecting emotional processes, was enhanced during shopping for luxury brands (vs non-luxury brands). LPP was especially prominent in the presence of others during purchase decisions, demonstrating the effects of social influences (Pozharliev *et al.*, 2015). In another study, the authors used scent inputs to understand emotional processing of olfactory stimuli by measuring LPP in detection and identification tasks (Lin *et al.*, 2016). The authors found that not only valence played a role in eliciting emotions revealed in negativity bias, but individual differences in sensitivity to smell also moderated the amplitude of LPP, suggesting a possible automatic inhibition of emotions. See Table II for additional details on LPP.

In the next section, we provide an overview of technical considerations and decisions we believe researchers should make when conducting an ERP study.

Considerations and decisions in conducting an event-related potential study

To reiterate, ERPs is one specific application of the EEG method, where a large number of trials are "time-locked" to understand perceptual or cognitive processes in response to sensory stimuli. To capture the high-quality ERP data used to infer and understand cognitive and emotional processes, the following three sections describe the considerations and decisions involved in the data collection and processing (often referred to as data cleaning) of ERP data. These sections outline considerations related to acquiring data and filtering noise, averaging and referencing and number of trials and electrodes. See Handy (2004), Luck (2014) and Picton *et al.* (2000) for more detailed background information and guidelines on ERP. Also refer to Light *et al.* (2010) for a step-by-step guidance on required materials and procedures for conducting an ERP study.

Acquiring data and filtering noise

Construction of ERPs requires temporal "locking" to events (e.g. a class of stimuli or responses) for multiple trials. This is done because recorded data originates from multiple brain sources including task-unrelated activity. In fact, because much of what is recorded at the scalp is unrelated to the event of interest, ERPs have a low signal-to-noise ratio (SNR). As such, it is important that many successive iterations of stimuli (i.e. number of trials, which will be discussed in a later section) be used to improve the ability to detect an ERP signal. Unrelated activity is assumed to vary randomly, and so "averaging" attenuates these potentials, leaving behind the ERPs (i.e. the ERPs) for further interpretation. (For example, if you recorded the earlier example chorus for an album, you could reduce singing-unrelated activity, such as someone sneezing, by averaging it with a second take. If the second take featured an audience cough, the combined new recording would reduce both the sneeze and the cough.)

Unfortunately, task-unrelated brain activity is not the only source of ERP contamination. Of particular concern are eye blinks and to a lesser extent cardiac responses and muscle movements. Due to close proximity to the scalp and possible systematic blinking to certain stimuli, eye blinks represent a serious challenge to ERP recordings that must be addressed. This is especially true at electrodes placed over the anterior portion (i.e. the area closer to the front) of the scalp. A wholly unrealistic assumption is that study participants would never blink across multiple trials. Therefore, as a first level of defense, participants are often asked to refrain from blinking as much as possible or to blink only to certain events of non-interest in the study. Luckily, many of these sources of noise are easily discernable within the raw EEG data. During an initial visual inspection, major sources of noise-related error are disregarded by excluding those trials. Some potential sources of error are also commonly dealt with during the post averaging phase (discussed in the next section).

Other sources of electrical noise are not altogether uncommon either. Typically, these sources include alternating current (AC) lines, AC lights and video monitors, and are handled through attempts at minimizing or eliminating their sources. Ideally, lab construction should be designed to minimize or eliminate sources of noise due to lighting, computer monitors and outside sources. Copper paint can be applied to walls of a specially designed recording chamber to shield AC currents, and electrical wiring within the walls can be insulated or eliminated. Direct current (DC) lights should be the only sources of light used within the chamber. For a lower-cost alternative, see Luck's (2005a, 2005b, p. 114) discussion of a Faraday cage.

Establishing a good connection between a participant's scalp and a recording electrode, a process referred to as reducing impedance, also helps to prevent recording environmental noise. An electrically conductive gel is inserted into the center of each porous electrode using a hypoallergenic blunt needle. Refer to Light *et al.* (2010) for pictorial demonstration of this procedure. The insertion of the gel includes briefly and mildly abrading the participant's skin to remove dead skin cells so as to establish a low degree of impedance (<5 KΩs). See Kappenman and Luck (2010) for a more thorough discussion of impedance.

Post manual removal of noise sources, filtering is usually applied to the raw EEG data. Most ERP responses of interest have frequencies between 0.5 and 20 to 30 Hz (Fabiani *et al.*, 2000). By comparison, possible sources of noise such as electromyographic signals (EMG), which are electrical signals originated from motor neurons in the muscle, and electrical line noise have frequencies higher than most ERPs. Because of this, it is common to apply a filter to attenuate noise outside of the range of interest. Common types of filters include low-pass filters, which allow only signals below a specified frequency to *pass* (e.g. 30 Hz), and high-pass filters, which filter out low-frequency activity. An intermediate approach called band-pass filtering passes frequencies within a specified range and attenuates those outside that range. It is important to be aware that filtering is a very tricky business and can lead to major distortions in ERP. As Luck (2005a, 2005b, p. 177) cautions:

> [. . .] as the frequency content of the signal and the noise become more and more similar, it becomes more and more difficult to suppress the noise without significantly distorting the signal.

It is therefore advisable to explore filtering approaches with an experienced ERP researcher before applying them in practice.

Averaging and referencing

The sometimes-referential nature of ERP can be confusing to new users of the technique. Baseline correction during averaging exemplifies this well. A general background characteristic of variability can exist within the ERP, independent of effects of interest. Because it is desirable to compare ERP between conditions or groups, it is useful to have a zero or neutral point relative to each condition or group to ensure that post-stimulus effects do not owe to pre-stimulus differences. To prevent this, Luck (2005a, 2005b) recommends a pre-stimulus baseline of 200 ms. See Figure 3 for a visual presentation of a baseline. Woodman (2010) discusses how, as a reviewer, he initially examines baselines in grand averaged figures (Figure 3) when assessing a paper's findings.

Differential amplification, which we referred to earlier, is another example of the referential nature of ERPs. Recording of EEG activity measures not individual activity at a single electrode *per se*, but rather differences between an active electrode (where scalp recordings occur) and a ground electrode (frequently FPz; see Figure 2 for a graphical representation of its scalp location) minus that of a reference electrode (discussed below) and a ground electrode. This is because voltage can be conceptualized as potential to move and the ground electrode is not immune to environmental contaminants (Luck, 2005a, 2005b). When a larger number of electrodes are used, computing an average reference offers some benefits including reduction of noise (for a review, see Dien, 1998). When operating with fewer electrodes, common approaches rely on linked electrodes on mastoids or earlobes, whereby reference measures are constructed offline so that the measurements are not influenced by left-right hemisphere differences. The nose is another reference site that is commonly used and is already hemisphere independent.

A final issue has to do with what is being averaged. ERP studies are especially suited for event-related designs. The temporal onset of the brain response to a stimulus may vary as a function of prior activity within the pre-stimulus interval. One approach to counteract this effect is by randomly adding jitter (as is common with fMRI; Yoon *et al.*, 2006). That is, adding a random but small temporal addition to between-trial fixations, which helps reduce the correlations between responses to stimuli (independent variables). Think of this as an announcement at a concert that your favorite song is about to be performed. For a two-hour concert, it can be tough to give your full attention to every song. As an alternative to adding jitter, one can increase distance between trials to 3-s plus a 1-s fixation. This interstimulus

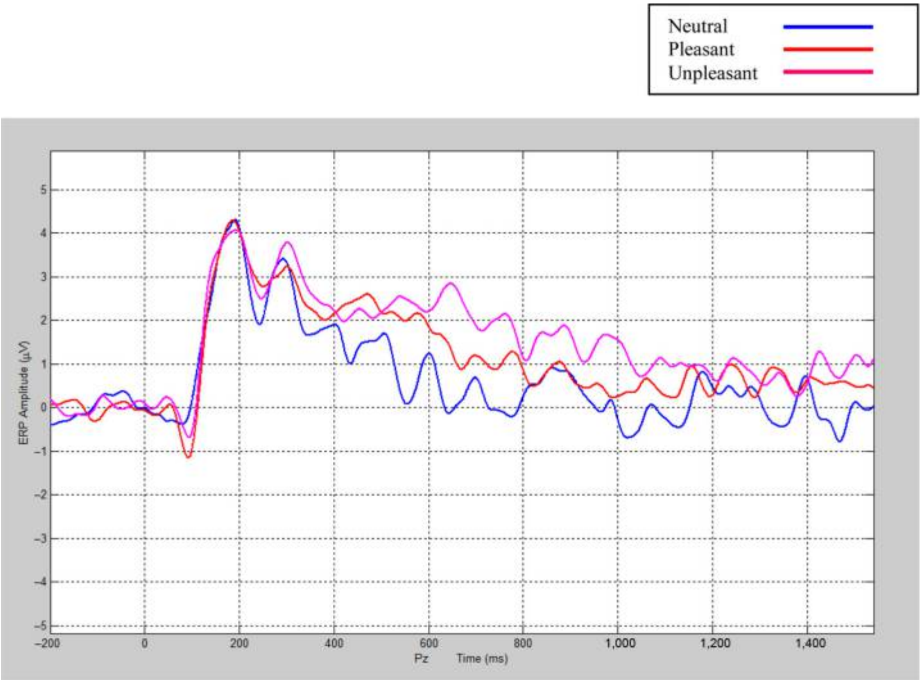


Figure 3.
Example of a grand average figure for the LPP component detected in a study on scent-related words

interval, a temporal interval between one stimulus and the next, is unlikely to suffer seriously from significant variation in onset latency of brain responses (Woldorff, 1993). Further analysis using mean amplitudes as dependent variables can also help to mitigate these effects (Luck, 2005a, 2005b).

Number of trials and electrodes

Finally, the number of trials and electrodes are worth mentioning. Because of SNR requirements of averaging, long trials and reductions in data due to noise, it is good to have an idea of the minimum number of trials needed, i.e. the number of trials you need to reduce the interference from task-unrelated activities. Fortunately, several studies have considered this issue for various components. For example, P3 which is a large component and is easily elicited, can be produced with as few as 20 trials (Cohen and Polich, 1997). Pontifex *et al.* (2010) showed that as few as 6-8 may be needed to accurately quantify ERN (and a related component called error positivity or Pe) in samples ranging from preadolescence to older adults. In contrast, Marco-Pallares *et al.* (2010) found that 50 trials were required to stabilize frontal-related negativity (a negative ERP-response to the presence of negative feedback) in older adults, but only 20 for younger adults. As a rule of thumb, at least 20 trials are recommended, although researchers should keep in mind their target ERP component of interest for adjustment.

Guidelines for the number of recording channels to use are hard to come by. Picton *et al.* (2000) bring up some of the main issues, which relate to whether the underlying scalp location is needed for observing a component, and potential interactions with task factors and scalp-related variables (e.g. hemisphere). For example, it would be difficult to isolate a

P3a (a P300 over the frontal scalp) without anterior electrode placements to compare to amplitudes over the posterior.

The next section compares the EEG method and the currently more commonly used fMRI approach, to further highlight the advantages of using EEG in consumer neuroscience research.

A comparison of electroencephalogram and functional magnetic resonance imaging approaches

In the past 35 years, a significant number of journals have emerged dedicated to the topic of cognitive neuroscience, featuring numerous EEG and ERP studies. To date, however, fMRI has dominated neuroscience methods in marketing and other business research fields. In marketing research, there has been a slow but steady increase in the number of fMRI studies over the past decade (Hedgcock and Rao, 2009; Reimann *et al.*, 2012; Reimann *et al.*, 2011; Yoon *et al.*, 2006). However, there are far fewer EEG studies (Boksem and Smidts, 2015; Jones *et al.*, 2012; Pozharliev *et al.*, 2015) in business journals, despite the considerable history of EEG studies in neuroscience and psychology (Luck, 2005a, 2005b). Marketing scholars have been slow to adopt EEG approaches, yet quicker to adopt the relatively newer, significantly costlier and technologically more complex, fMRI technique.

Furthermore, Rugg and Coles (1995) note that functional neuroimaging is front and center when it comes to identifying brain regions associated with different cognitive operations. However, as they also note, and still holds true, fMRI also lacks temporal resolution; hence, findings can only be described as correlational relationships. This limits fMRI's value in the study of cognitive dynamics and its neural sources. Other advantages ERP and EEG provide over fMRI, beyond temporal precision, include the more natural setting (sitting upright), portability (with the more recent dry cap models) and lower acquisition or per subject costs, allowing wider research accessibility. An fMRI study setup would cost approximately 5 to 12 times more than a comparable EEG study. Thus, for an fMRI study involving 35 subjects, a budget of at least $25,000 is recommended, whereas, budgeting for an EEG study with the same number of subjects should be approximately $2000-$4000. The use of the fMRI machine and lab time ranges from about $500 to $700 per subject, plus $100 compensation for the subject. In contrast, machine and lab time use for an EEG study is typically around $50/h; depending on the length of the study, one subject in an EEG study costs approximately $60-$80. See Solnais *et al.* (2013, p. 71) and Plassmann *et al.* (2007, p. 156) for a direct comparison of EEG, fMRI and other neuro-based methods highlighting the advantages and drawbacks of each method. Table III summarizes the highlighted differences between EEG and fMRI approaches.

Table III.
Comparison of EEG and fMRI

Factor	EEG	fMRI
Per subject cost	Lower	Higher (5-12×× more)
Technology	Less complex	More complex
Research history	Longer	Newer
Temporal resolution	Yes	No
Identification of brain regions	No (possible with source localization technology)	Yes
Setting	Upright sitting (more natural)	Lying in a MRI machine
Portability	Yes (w/dry cap models)	No
Post-study cleanup	Yes (w/traditional caps)	No

It is important to bring the researcher's attention to another related method, MEG, which is similar to EEG and which we briefly highlighted earlier, as it measures ongoing brain activity at the millisecond level and is also characterized by high temporal resolution. MEG is also a non-invasive technique and detects magnetic fields produced by the brain. Unlike EEG, magnetic fields detected using MEG are not easily distorted by tissues of different conductivity. Therefore, source localization models can be conducted in MEG with simpler models than EEG. Another difference between MEG and EEG is that MEG does not require the reference electrode that is needed in EEG recordings.

Another example of potential complementary techniques is the combination of EEG and fMRI. Reimann *et al.* (2011), in their review of the popular use of fMRI in consumer neuroscience research, acknowledge that other techniques often complement fMRI studies. They note that:

> While fMRI provides a good spatial resolution of the brain, EEG offers advantages in terms of temporal resolution, which describes the time between actual activation in the brain and measurement (Rossiter *et al.*, 2001; Reimann *et al.*, 2011).

We agree and provide two examples of the complementary nature of fMRI and EEG methodological approaches in the next section.

Combining event-related potential and functional magnetic resonance imaging approaches to enhance consumer research

We consider two well-known fMRI studies in marketing, and conjecture about how ERP could be used to further enhance our knowledge within the areas of inquiry. First, we consider Yoon *et al.*'s (2006) fMRI study of brand personality, which challenges the prevailing assumption that brands are processed like personality judgments. Specifically, these authors find that person-related judgments activate medial prefrontal cortex (MPFC) areas more so than brand judgments.

One-way ERP could be used with their experimental design is to ascertain how soon these processes deviate. A possible component of interest such as LPP may be a putative neural component of the divergence point. As Qin *et al.* (2009) point out, MPFC and LPP have consistently been found to relate to evaluation processes during social judgments. If person judgments elicit greater LPP than brand judgments, this would offer compelling evidence that person judgments rely on enhanced emotional memory, a process which may also exhibit an earlier temporal onset.

Another possibility is an earlier component known as N170. Although not the focus of their study, Yoon *et al.* (2006) briefly address the possible specialization of a region of the fusiform gyrus for facial recognition. N170 is a sensory-obligatory component of the visual system and a widely studied possible corollary of facial processing (Eimer, 2011). To the extent that person judgments like those used in Yoon *et al.* (2006) are mediated by recall of facial information, N170 enhancement, early onset, or both, would suggest a rapid, somewhat reflexive divergence of human versus brand judgments.

In another fMRI study, Hedgcock *et al.* (2012) sought to test a two-stage model of self-control depletion. Specifically, the authors were interested in whether self-control depletion related more to identifying a conflict or implementing control. The authors used BOLD response and defined activation in the anterior portion of the cingulate cortex (ACC) as their marker of conflict identification, and activity in the lateral prefrontal cortex, as related to control implementation. Beyond the limitations of using a temporally imprecise brain measure (fMRI) to test a temporal model, the authors do provide an impressive second study whereby a manipulation designed to enhance implementation control, their stage two, in fact does. Whether one can reduce say conflict identification to anterior cingulate activity is open to debate, though to be fair, they do not purport to do so.

Not directly tested in Hedgcock *et al.*'s (2012) model, one alternative explanation is that how brain regions couple together, a concept referred to as functional connectivity, is more important with respect to ACC in conflict identification than regional cerebral activation. An ERP approach to test the temporal model outlined in Hedgcock *et al.* (2012) might fashion their design to elicit ERN. Classically elicited in an error-commission paradigm, ERN is a negative deflection over the anterior scalp that is usually observed within 200 ms of error commission. ERN is thought to be related to ACC function and may be sensitive to phasic dopamine activity in ACC (Cockburn *et al.*, 2014). As noted in the previous section, ERPs are sensitive to *summated* brain activity, and sensitivity to dopamine neurotransmission is an advantage of the ERP approach as neurotransmitter systems project to broad neural regions. As such, ERN may serve to be a more useful indicator of self-control implementation to the extent that it is more sensitive to the neural network responsible for it.

These examples illustrate how ERP techniques could be used to augment existing fMRI studies published in the field of marketing, or partner with future fMRI projects, demonstrating the potential synergies in using multiple neuroscience approaches together in our discipline. In addition, ERP techniques could also be partnered with other qualitative or quantitative methodologies to provide physiological indicators, garnering additional insights into the phenomenon under study.

Other multi-method approaches using electroencephalogram

Two potential ways to extend fMRI studies using an ERP approach were just discussed; however, there are several other notable examples of the successful use of multiple methods. Ohme *et al.* (2009) used EEG, along with galvanic skin response (GSR) and facial electromyography (EMG), to capture affect and emotions in response to two versions of the same ad. EMG has been shown to be effective in capturing facial muscle movement to infer facial expressions associated with emotions. Another neurophysiological measure, the skin conductance (SC) technique, which measures activation of the autonomic nervous system, captured arousal. Both EMG and SC have been shown to be more accurate than self-report measures (Hazlett and Hazlett, 1999; LaBarbera and Tucciarone, 1995). In this example, the use of other biometrics complement the EEG results and provide additional evidence of the processes studied.

In another example of successfully combined methods, Vecchiato *et al.* (2010) recorded EEG simultaneously with GSRs, also known as SC, and heart rate (HR) measures, to capture activity during highly memorable and pleasant TV ads. Cerebral activity captured with EEG was complemented with autonomic responses detected via GSR and HR. The autonomic variables were compared between the conditions on memorable (vs unmemorable) and pleasant (vs dislike) aspects of the ads. In their study, Vecchiato *et al.* (2010) treated the three neurophysiological measures as separate indices to record the reactions to high memorable and high pleasant TV ads. This use of a multi-method approach, encompassing EEG data, focuses on triangulating findings across different sources of data.

Another application of multiple methods demonstrates a more holistic approach. This was done in a massive project by Venkatraman *et al.* (2015) where data were collected using a combination of six different methods, including traditional self report, EEG, fMRI, biometrics (including HR, SC and respiration rate), eyetracking and implicit attitude tests to examine four different constructs. Each method focused on studying a separate cognitive process, and the goal was to link these measures with higher level constructs often used in advertising, such as attention, affect, memory and desirability (Venkatraman *et al.*, 2015). Correlations between the measures from the different methods were conducted and compared to find the best predicting (explanation of variance) combination of neurophysiological measures.

Most recently, Barnett and Cerf (2017) used EEG to predict movie ticket sales, in combination with other physiological measures such as HR, respiratory rate and SC. Their results demonstrated the better predictability of EEG in comparison with these physiological methods. They used multi-methods as a technique to demonstrate the advantages of the EEG has in capturing cognitive processes over other physiological measures.

These examples clearly demonstrate that a multi-method approach leverages the advantages of each method and helps to provide a more complete response to the particular research question.

Summary and conclusion

In their paper, Plassmann *et al.* (2015) proposed five marketing applications of neuroscience methods. In this paper, we present a review of past and current marketing research that use an EEG approach to study consumer behavior, and further demonstrate that these five applications are indeed realistic and generalizable to EEG-based research. The studies highlighted demonstrate that consumer neuroscience, and EEG in particular, cannot only be used to study an array of cognitive processes that are relevant to consumer research, but also, when used appropriately, can have an advantage over traditional methods.

First, the temporal precision of EEG allows researchers to capture acute responses to common marketing topics related to advertising, pricing, branding and product introductions. Additionally, EEG's relatively low cost in setting up the equipment and acquiring data should attract widespread use, not only by practitioners but also by academics. Therefore, to foster wider application of the EEG approach and ERP method in consumer research, our paper provides an introduction to EEG terminology and technology for researchers that either have an interest in conducting studies using this method, or simply wish to better understand papers that do undertake an EEG approach.

However, it is worth noting that, like fMRI studies and other neuroscience methods, EEG results should be interpreted with care. Just as each brain region is not appointed to only one cognitive or behavioral function, brain waves and ERP components are not meant to be simple indexes to explain cognitive or behavioral outcomes. In other words, deductive reasoning should be used with caution. Interpretation of the results should take into consideration the complexity of the experimental design, including the nature of the stimuli, the paradigm used and other method-induced variances.

Finally, like all methodological approaches, EEG methods do have their limitations. A common complaint against the use of neuroscience methods to study consumer behavior is the use of relatively small sample sizes, perceived as resulting in low statistical power. However, this perceived limitation is often due to the following misperceptions regarding neuroscience data:

- the common fundamental biological composition of the brain does not vary as widely as other behavioral variables;
- the experimental design used for conducting neuroscience studies, whether it is the procedures or the stimuli, is much more controlled in comparison to behavioral experiments; and
- in the case of EEG studies, the number of trials per subject included in a study is relatively large.

Depending on the characteristics of the target ERP component as discussed earlier, it could be as minimal as 20 in P3 or up to 100 in an early component such as P100. Using simulation experiments to estimate the ideal sample size in neuroimaging studies, Desmond and Glover (2002) estimate at least 12 subjects are needed (and up to 25) to ensure 80 per cent statistical power, with the general practice being to employ 6 to 10 subjects per condition (Hirsch, 2010). In their review of 33 consumer neuroscience studies using EEG and fMRI methods, Solnais *et al.* (2013) noted that an average of 24 subjects were included in each study. However, this number does not consider the possible use of a between subject design. In fact, half of the studies they reviewed included a range of 10-19 subjects.

Another perceived limitation of EEG imaging is its spatial resolution. However, with the advancement of EEG technology, source localization techniques are continuously advancing, and the standards for temporal and spatial resolution have improved from at least 5 ms and 5 mm, respectively, since Baillet and Garnero (1997). Although not a focus of discussion in this paper, it is worth noting that advanced mathematical algorithms such as LORETA and sLORETA (Bradley *et al.*, 2016) are gaining popularity in research fields such as neuroscience, psychology and even marketing (Cook *et al.*, 2011; Daugherty *et al.*, 2016). See Slotnick (2004) for an introduction to this exciting and developing area of ERP analysis.

Another way to combat the perceived limitations of EEG is to triangulate the findings from using an EEG approach, with data from other qualitative and quantitative techniques, or even other biometric or neurophysiological measures. Like Plassmann *et al.* (2015) and other similarly minded researchers, we advocate the use of a multi-method approach to strengthen the results from using neuroscience methods, like EEG.

Consumer neuroscience is a growing subfield in the area of marketing research – a sub-area that is here to stay. As marketing researchers, it is to our advantage to become familiar with the various methodological approaches, including EEG and ERP, which allow us additional insights into the behavior of consumers. This paper is one step toward fostering a deeper understanding of the application of the EEG approach in consumer neuroscience.

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Corresponding author
Meng-Hsien (Jenny) Lin can be contacted at: jelin@csumb.edu