Neurobiological Measures

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Measuring Exposure and Attention to Media and Communication

8. Neurobiological Measures

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Abstract

We discuss what neurobiological measures can (and cannot) reveal about media exposure (section 8.2), followed by a discussion of recurrent validity and reliability issues and attempts towards their mitigation (section 8.3). In the end, we briefly discuss how technological advancements and rising societal questions may shape the future of psychophysiological media research.

Keywords: EEG, fMRI, fEMG, heart rate, skin conductance, validity

8.1 Introduction

Media exposure is an inherently dynamic process (A. Lang, 2000; A. Lang & Ewoldsen, 2010). Whether we are watching TV, listening to music, or scrolling through the latest news feed, our brains continuously parse incoming sensory information into coherent, interconnected, and meaningful units. Notably, these complex computational transformations often appear intuitively and without conscious awareness, owing to the evolved, functionally-specialized circuits that constitute our neurobiological make-up (Tooby & Cosmides, 2001).

The conceptualization of media exposure as a dynamic process enabled and orchestrated by an ensemble of biological systems — has sparked an exciting, interdisciplinary field of research (for overviews, see Bolls et al., 2019; Floyd & Weber, 2020). At the same time, the paradigm shift from behaviorism towards information processing (Chaffee, 1980) has also raised an intricate methodological debate: Can we reliably measure the opaque cognitive processing of media content in real time? In this chapter, we review efforts to tackle this question, providing the reader with a critical discussion of psychophysiological measurements that monitor individuals

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during media exposure. Rather than developing a comprehensive introduction and inventory (see R. Potter & Bolls, 2012), we herein take a broader perspective, focusing on what dynamic measures can (and cannot) reveal about media exposure.

8.2 Types of measures

According to the neurophysiological perspective (NPP, Weber et al., 2008), the brain is the central information processing system that parses and integrates incoming sensory sensations and thus provides a powerful gateway for observing how media content is processed in real time. While some studies directly relate brain activity to media processing (see EEG/fMRI below), other prominent psychophysiological measures follow a more indirect route. Here, perception, thinking, feeling, or consciousness are conceptualized as side-effects of an "embodied brain," and we can measure these side effects of brain function using psychophysiological tools (A. Lang et al., 2009). For example, think of the last time you watched a suspenseful scene from an action movie. Perhaps your hands were starting to become sweaty, and your heart rate may have even decelerated slightly. In turn, psychophysiological researchers are interested in how *physiological* changes (e.g., skin conductance and heart rate) index *psychological* events (e.g., arousal, fear) that occurred during media exposure. Taken together, adopting a neurobiological approach to media exposure implies that body, brain, and media jointly act and interact over time, and that describing the interactions between these complex, dynamic systems can reveal how media content gives rise to distinct psychological responses (A. Lang et al., 2009). Following this perspective, we now provide a selection of neurobiological concepts and methods relevant to media exposure research.

Affective responses to media exposure

Affect is a central concept in theories of media exposure such as the Differential Susceptibility to Media Effects Model (Valkenburg & Peter, 2013b). Here, the affective responses are the immediate physiological responses to media exposure. These physiological responses are largely uncontrollable and occur very fast after exposure (between 50 and 100 milliseconds after exposure to a stimulus), while more cognitive evaluations come later (roughly after 500 milliseconds, Lodge & Taber, 2013). These different temporal receptive windows are embedded within a larger processing hierarchy (Hasson et al., 2008) that enables the brain to parse and integrate incoming sensory information (e.g., sounds to words, words to phrases, phrases to paragraphs, etc.).

The circumplex model of affect (Russell, 1980) distinguishes arousal and valence as the two core affective dimensions. Arousal captures the intensity of affect and can be indexed with skin conductance. Valence captures the direction (positive or negative) of affect and may be measured with facial Electromyography (fEMG, see below). Here, we discuss the core characteristics and applications in media exposure research for two affective dimensions: arousal and valence.

Arousal captured with skin conductance. Skin conductance captures the activity of the sympathetic nervous system which is part of the autonomic nervous system (Dawson et al., 2017). Skin conductance measures the varying electrical properties of the skin in response to the increase of sweat secretion in the eccrine glands (for an introduction, see Soroka, 2019). With more sweat secretion, the conductance of electricity improves, and skin conductance levels rise. This increase in skin conductance is interpreted as an increase in arousal. Skin conductance has been used to capture heightened arousal in response to negative images (P. Lang et al., 1993), negative news (Soroka et al., 2019; Soroka & McAdams, 2015), uncivil political debates (Mutz, 2007; Mutz & Reeves, 2005), tobacco ads (Leshner et al., 2022; Clayton, 2022), self-transcendent videos (Clayton et al., 2021), group eating food cues (Liu & Bailey, 2021), political rhetoric (Boyer, 2021), and negative political ads (Wang et al., 2014). Soroka and colleagues, for instance, showed that negative vs. positive news caused an increase in physiological arousal (Soroka et al., 2019; Soroka & McAdams, 2015). Noteworthy, the results of Soroka et al. (2019) were largely uniform for samples of 17 countries across all six continents. In another study, Bakker, Schumacher, et al. (2021) found that listening and watching short messages about contemporary societal issues like immigration, climate change, and inequality increases physiological arousal and that this is especially the case among people with more extreme political attitudes. To summarize, skin conductance is a useful tool to capture arousal during media exposure.

Valence captured with facial Electromyography. The second dimension of affect in the circumplex model is valence. Valence can be captured using facial Electromyography (fEMG). Specifically, tiny (not observable) muscle contractions in a specific facial region induce bioelectric signals at the surface of the skin in the face. fEMG captures these bioelectric signals (R. Potter & Bolls, 2012). An advantage of fEMG is that it detects rapid changes in the contractions of facial muscles over time (van Boxtel, 2010), making it possible to link media processing and physiological responses at a high temporal resolution.

The *corrugator supercilii* muscle region (above the eyebrow) captures negative affect. Corrugator activity has been recorded in response to negative images (P. Lang et al., 1993), and negative words (Hietanen et al., 1998). The *zygomaticus major* muscle region (pulls the corners of the mouth into a smile, Larsen et al., 2003), captures positive affect. Zygomaticus activity increases in response to positively valenced images (van Oyen Witvliet & Vrana, 1995) and videos (Cacioppo et al.,1986). Other muscles have been associated with specific discrete emotions, such as the *levator labii*, which is associated with disgust (Chapman et al., 2009). Bakker, Schumacher, and Homan (2020), for instance, showed that participants had strong labii responses to a politician from the out-party versus the in-party. Moreover, participants experienced an increase in labii activity once a politician of the in-party (compared to the out-party) committed a moral violation.

Along these lines, studies exposing people to various forms of media content show that negative affect in media content causes corrugator activity. For instance, listing to radio advertisements, listeners showed a greater corrugator response "following the onset of negatively valenced words compared to positively valenced words" (Lee & R. Potter, 2020, p. 1154). Likewise, watching highway safety videos featuring a high aversive tone increased corrugator activity compared to a video with a low aversive tone (Howell et al., 2018).

Yet, when the corrugator activity is paired to what people say they experience, a different pattern emerges. Homan et al. (2022), for instance, find that participants relaxed their corrugator muscle in response to in-party politicians' emotional displays, irrespective of the emotion the in-party politician displayed. But participants report feeling significantly angrier when watching an in-party politician display anger compared to a neutral or happy expression of the same politician. Similarly, Bakker, Schumacher, and Rooduijn (2021) showed that listening to incongruent messages lead to an increase in corrugator activity. This corrugator activity was basically uncorrelated with self-reported discrete emotions, but the increase in corrugatory activity predicated post-treatment attitude change.

To summarize, fEMG seems especially relevant in contexts in which participants have no or suppressed cognitive access to their affective responses, or in cases where they may be unwilling to report their views (e.g., due to social desirability). This may be quite common in media exposure studies, especially when dealing with contested topics like politics in modern Western democracies.

Attention captured with heart rate variability

Attention to specific content features naturally is of core interest to researchers interested in understanding how media users dynamically register incoming information (Fisher et al., 2023). We focus our discussion on heart rate variability here. In media exposure research, heart rate variability is used to measure (cognitive) attention (A. Lang et al., 1996; Soroka et al., 2019; Soroka & McAdams, 2015)[1]. A few recent studies illustrate the potential use of heart rate variability — as a measure of attention — for media exposure. Soroka and colleagues find that there is an increase in heart rate variability in response to negative vs. positive news (Soroka et al., 2016; Soroka et al., 2019; Soroka & McAdams, 2015). The authors interpret these results as evidence that people express more attention to negative vs. positive news. Dunaway and Soroka (2021) asked whether information processing differs when people consume information on a smartphone or on a larger computer screen. Dunaway and Soroka (2021, p. 69) explain that the "results suggest lower levels of cognitive access" as captured with heart rate variability "to video news content on a mobile-sized screen" compared to the normal screen. Dunaway and Soroka (2021) conclude that their study has "potentially important consequences for public attention to current affairs in an increasingly mobile media environment" (p. 69). However, Bakker, Schumacher, and Rooduijn (2021), for instance, found no indication that exposure to counter-attitudinal messages, captured in a campaign-ad style — increases attention (e.g., no statistically significant increase in heart rate variability) — as the theory of motivated reasoning would lead us to expect as counter-arguing takes effort (Lodge & Taber, 2013). Taken together, these studies illustrate heart rate variability is a useful tool for capturing attention to media.

fMRI

In the past decade, functional magnetic resonance imaging (fMRI) has established itself as an appropriate neurophysiological method for examining cognitive responses during dynamic media exposure (for a recent review, see Hopp & Weber, 2020). In a nutshell, fMRI relies on the magnetic properties of hemoglobin to measure the contrast of oxygenated to deoxygenated blood at

1 Sometimes heart variability is also seen as a measure of arousal but any acceleration in heart rate that comes from arousal will be overwhelmed by the deceleration that comes with attention (R. Potter & Bolls, 2012).

a high spatiotemporal resolution, thereby serving as an indirect assessment of neural activity. Before conducting an fMRI study, media researchers typically define a set of brain regions (Regions of Interest [ROIs]) or networks of ROIs whose activity is known to correlate with a psychological concept or process of interest (e.g., aggression, valuation, or attention; but see Poldrack, 2006) and then observe how neural activity in these ROIs dynamically changes in response to certain media content features. Hence, fMRI is a useful tool for continuously interrogating a range of latent cognitive processes relevant to media exposure research, including attention (Huskey et al., 2018), narrative engagement (Grall et al., 2021), valuation (Scholz et al., 2017), counterarguing (Weber et al., 2015), or affective experiences (Chan et al., 2020).

In one of the first studies employing fMRI during media exposure, Weber et al. (2006) showed that playing a violent video game suppressed affective areas of the anterior cingulate cortex (ACC) and the amygdala, highlighting the potential of virtual violence for inducing aggressive cognitions. Almost simultaneously, Hasson et al. (2004) demonstrated that neural activity in the visual cortex is highly correlated across subjects watching the same movie, revealing that individual brains show a surprising tendency to “tick collectively” during natural vision. Since these seminal studies, fMRI has successfully been applied to delineate the neural correlates of counterarguing during anti-drug messages (Weber et al., 2015), the valuation and information virality of news (Scholz et al., 2017), the synchronization of attention and reward brain networks during media induced flow experiences (Huskey et al., 2018), and even the ideologically aligned and idiosyncratic brain responses during politically polarized perception (van Baar et al., 2021).

A key advantage of fMRI over previously described psychophysiological measurements is its *multivariate* recording of neural activity. By examining the neural activity “pattern” (i.e., covariance) within ROIs or even the whole brain, recent work has demonstrated that distinct psychological events, from discrete emotions (Kragel et al., 2019) to moral intuitions (Hopp et al., 2022), can be “decoded” from underlying brain representations. This Multivariate Pattern Analysis (MVPA, Norman et al., 2006) holds great potential to push psychophysiological measurements beyond broader dimensions of cognition and affect (cf. the circumplex model of affect) towards more fine-grained *semantic* interpretations of media content. For example, Hopp (2021) used MVPA and found that Republicans and Democrats in the US experience different moral violations when processing the same political attack advertisements, thereby revealing a “morality bias” that could explain ongoing polarization and out-party animosity.

While the above studies only provide a glimpse of past research, they succinctly demonstrate the method-theory synergy that inspires the exciting field of media neuroscience (Weber et al., 2018). At the same time, access to MRI facilities, average scanning costs, and a steep technical learning curve have hindered communication researchers from incorporating fMRI into their methodological arsenal. Yet, powerful and cost-effective alternatives to fMRI have been applied in media exposure research, including electroencephalography (EEG, Morey, 2018) and functional near infrared spectroscopy (fNIRS, Dieffenbach et al., 2021). We believe that fMRI is a useful tool for our understanding of the effects of media exposure on individuals.

8.3 The perils of physiological measures for media exposure research

In the previous section, we reviewed how psychophysiological measurements, informed by theoretical advancements in biology and cognitive neuroscience, have pushed the envelope of media exposure research. At the same time, psychophysiological tools have their respective limitations and offer no panacea for studying media exposure. Accordingly, we now turn to a discussion of the common perils that have stymied psychophysiological research, and offer several solutions to minimize erroneous interpretations and questionable research practices (QRPs, Bakker, Jaidka, et al., 2021).

Methodological considerations: validity, reliability and open science

Advancements in engineering will naturally continue to improve the fidelity and reliability of psychophysiological measurements. However, we must not forget that the opportunities of neurobiological measures for advancing media exposure research are fundamentally constrained by our understanding (and experimental control) of the independent variable: media *content*. Thus, it is imperative that in designing our studies, we make sure to, by design, rule out potential confounding variables. One possibility is for the researcher to produce the stimuli (see Bakker, Schumacher, & Rooduijn, 2021). Yet, often media researchers would want to use naturalistic stimuli (see Soroka et al., 2019). In that case it is important, to be rigorous in content analyzing stimuli to rule out confounds that may unknowingly modulate psychophysiological responses (Grall & Finn, 2022). Here, recent developments in computer vision and signal processing offer media researchers powerful, automated tools for extracting a range of audiovisual features known to correlate with psychophysiological responses, including amplitude, scale, or frame centrality (Malik et al., 2022). Combined with a carefully controlled, pre-tested, and pre-registered study design, we increase our power to isolate effects and draw solid causal inferences.

Moreover, a largely unexplored question is the extent to which neurobiological measures and more cognitive and reflective measures such as self-reported thoughts and emotions should align. For instance, one critique towards skin conductance is based upon the fact that physiological responses to threatening images did not — or very weakly — correlate with self-reported affective responses to the same images (see for instance, Osmundsen et al., 2022). This lack of concordance is actually not evidence for the lack of validity of one measure over the other. Physiological measures are tapping into other aspects of affect than the self-reports do (Keltner & Gross, 1999). It is therefore not a question of which is "better"; these measures are simply tapping into different aspects of affect. In fact, we think that one of the big puzzles in the field is to outline when and under which conditions physiological and self-reports align or not (see also, Bakker, Schumacher, Gothreau, & Arceneaux, 2020; Bakker, Schumacher, & Rooduijn, 2021).

At the same time, we encourage scholars to critically assess the predictive validity of the neurobiological measures as well as the self-reported measures. Here there might be different options. First, neurological and self-reported responses have independent effects on the outcome of interest (see for instance Bakker, Schumacher, & Rooduijn, 2021; LeDoux & Pine, 2016). Alternatively, one could argue the predictive validity of the neurobiological responses is the strongest when it is aligned with a more cognitive response (for a similar argument, see Bakker, Schumacher, & Homan, 2020). Others might argue that the self-reported effects are the strongest on other self-reported measures, while more neurobiological measures have stronger effects on other implicit measures (Evers et al., 2014). We do not know what is the correct answer, yet. However, we do advocate for a multi-level, pluralistic approach when understanding the brain–behavior–media relationship (see Marr's tri-level framework, Huskey et al., 2020). Behavioral and self-report work is often a necessary first step to understanding *why* a behavior occurs (e.g., selecting negative over positive news), after which psychophysiology can reveal *how* this behavior is physically instantiated (e.g., heightened attention and arousal towards negative information).

Furthermore, it will not come as a surprise to the reader of this chapter (and book) that laboratory-based studies lack ecological validity (Bronfenbrenner, 1979; Nastase et al., 2020). It is not natural to read, watch or listen to news (or other media content) while sitting in an artificial (almost hospital-like) laboratory environment while connected to a set of wires to your body (in the case of physiology) or even laying down in a large and noisy magnet (in case of fMRI). Technological advancements, however, have led to an increase in wearable equipment. As a consequence, neurobiological measures can now be collected in more natural environments: wristbands can for instance capture physiological arousal (Bolinski et al., 2021; Konvalinka et al., 2011). Using these and other wearable devices, it becomes possible to study people at home, at school, among their friends, or at any other place where people process media content. We think there is a lot of unexplored ground to study the neurobiological responses to media exposure outside the classical laboratory setting. If and how the conclusions of studies discussed in this chapter will differ, or will remain the same, is an open-ended question. Regardless of the answer, we think such ecological studies will make important contributions to our understanding of the neurobiological responses to media exposure.

Finally, media exposure studies that rely upon neurobiological measures need replications of seminal, foundational studies to learn more about their replicability and/or generalizability (McEwan et al., 2018). We also encourage scholars to preregister their hypotheses, design, sample size justification, and analysis strategy. A priori power analyses — and more in general sample size justification — should become the standard (Lakens, 2022). Adopting these open science practices will lead to more studies that can reliably detect the (often small) effects of interest. Ultimately, adopting this will increase the credibility of using neurobiological measures for media exposure research.

8.4 Concluding remarks

In this chapter, we have provided the reader with a rough overview of possible neurobiological theories and methods that can be used in media exposure research. We hope the reader treats this chapter as a starting point. For us, the two most important take-home messages are as follows: First, information processing is too complex to solely rely upon behavioral and self-reported measures. Our body is responding in a much more complex way to media exposure. This leaves us with our second take-home point. The neurobiological responses to media exposure call for interdisciplinary partnerships: psychologists and neuroscientists bring their expertise when it comes to the neurobiological mechanisms, while communication researchers bring their rich understanding of media exposure, coupled with methodological expertise in content analysis. Together, these partnerships have a unique contribution to make. As a consequence, the neurobiological responses during media exposure are too complex to leave to one particular discipline but call for exciting interdisciplinary collaborations.

To conclude, we think that neurobiological theories and methods deserve a place in the toolbox of communication researchers: if we want to study the full complexity of responses to media exposure, then neurobiological theories and methods belong in the toolbox. This requires researchers to learn new theories and new methods or join interdisciplinary collaborations.

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