

A Scoping Review: Neuromodulation in Consumer Buying Behaviour – Mapping the Emerging Landscape

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ABSTRACT

Background: Neuromarketing has emerged as a field that applies neuroscience tools to understand consumer decision-making. However, the concept of **neuromodulation** – the targeted alteration of neural activity through external stimuli – represents a distinct and potentially more powerful paradigm for influencing consumer behavior at a neurophysiological level.

Objective: To systematically map the existing literature on neuromodulation techniques applied to consumer buying behavior, identify the range of neuromodulatory interventions studied, critically appraise the evidence quality, and establish a research agenda for this emerging field.

Methods: A scoping review was conducted following the Arksey and O'Malley framework and PRISMA-ScR guidelines. A systematic search was performed across PubMed, Scopus, Google Scholar, and Web of Science from inception to March 2026. The Mixed Methods Appraisal Tool (MMAT) was used for quality assessment of included studies.

Results: Of 98 records identified, 21 studies met inclusion criteria. Quality assessment revealed that 62% of studies were of moderate to high quality, with case series and proof-of-concept studies dominating the evidence base. The evidence mapped across three primary neuromodulatory approaches: **1) Caloric Vestibular Stimulation (CVS)** demonstrating reduced purchase probability via insular cortex modulation; **2) Transcranial Magnetic Stimulation (TMS)** affecting valuation and preference formation in prefrontal regions; **3) Transcranial Direct Current Stimulation (tDCS)** with emerging evidence for consumer choice modulation. **Critical gap:** The majority of studies focus on measurement (neuromarketing) rather than modulation (neuromodulation), with only CVS studies directly testing causal neuromodulatory effects on buying decisions.

Conclusion: Neuromodulation of consumer behavior is an emerging but underdeveloped field. Caloric vestibular stimulation provides proof-of-concept that non-invasive brain stimulation can causally affect purchase decisions. Future research should prioritize replication studies, exploration of tDCS applications, and development of ethical frameworks.

Keywords: Neuromodulation, Consumer buying behavior, Consumer neuroscience, Caloric vestibular stimulation (CVS), Purchase decision

INTRODUCTION

Background : Consumer buying behavior has traditionally been studied through self-report surveys, focus groups, and behavioral experiments. While these methods provide valuable insights, they are subject to social

desirability bias, recall limitations, and the fundamental challenge that consumers often cannot articulate the subconscious drivers of their decisions [1].

Neuromarketing emerged in the early 2000s to address these limitations. Defined as the application of neuroscience tools to understand consumer responses to marketing stimuli, neuromarketing has primarily focused on **measurement** – using EEG, fMRI, and eye-tracking to observe brain activity during exposure to advertisements, products, or pricing [2]. These observational techniques have revealed that purchase decisions activate specific brain regions, including the insular cortex, nucleus accumbens, and prefrontal cortex [3].

From Neuromarketing to Neuromodulation

A conceptual distinction is critical for this review:

Concept	Definition	Approach	Example
Neuromarketing	Measuring brain activity to understand consumer responses	Observational / Correlational	fMRI showing insula activation during price processing
Neuromodulation	Altering neural activity to influence consumer behavior	Causal / Interventional	tDCS or CVS changing purchase probability

While neuromarketing has generated a substantial literature, **neuromodulation in consumer contexts** remains relatively unexplored. Neuromodulation refers to the targeted alteration of nerve activity through delivery of a stimulus – electrical, magnetic, mechanical, or thermal – to specific neural sites [4]. Techniques include:

- **Caloric Vestibular Stimulation (CVS):** Thermal stimulation of the vestibular system
- **Transcranial Magnetic Stimulation (TMS):** Magnetic pulses to cortical regions
- **Transcranial Direct Current Stimulation (tDCS):** Low-amplitude electrical current
- **EEG-based Neurofeedback:** Real-time brain activity training

Rationale and Objectives

The distinction between measurement and modulation is not merely semantic. If neuromodulation can causally affect purchase decisions, it has profound implications for understanding the neural causality of consumer behavior, developing interventions for problematic purchasing (e.g., compulsive buying), and addressing ethical considerations regarding consumer manipulation.

This scoping review aims to:

1. Systematically map the literature on neuromodulation applied to consumer buying behavior
2. Identify the range of neuromodulatory techniques and their reported effects
3. Critically appraise the quality of existing evidence
4. Distinguish between measurement-focused (neuromarketing) and modulation-focused (neuromodulation) studies
5. Establish a research agenda for this nascent field

METHODS

Scoping Review Framework

This review followed the Arksey and O'Malley (2005) framework for scoping reviews, which is appropriate for mapping emerging fields with heterogeneous methodologies [5]. The PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) guidelines were followed [6].

Research Questions

1. What neuromodulation techniques have been applied to study or influence consumer buying behavior?
2. What are the reported effects of neuromodulation on purchase decisions, product preferences, and willingness to pay?

3. What neural mechanisms have been implicated in neuromodulation of consumer behavior?
4. What is the quality of existing evidence?
5. What are the primary evidence gaps in this emerging field?

Search Strategy

A systematic search was performed across four databases: **PubMed, Scopus, Google Scholar, and Web of Science**, from database inception to March 2026.

Search terms (combined with Boolean operators):

- **Neuromodulation terms:** "neuromodulation" OR "brain stimulation" OR "transcranial magnetic stimulation" OR "TMS" OR "transcranial direct current stimulation" OR "tDCS" OR "caloric vestibular stimulation" OR "CVS" OR "neurofeedback"
- **Consumer terms:** "consumer behavior" OR "consumer buying" OR "purchase decision" OR "willingness to pay" OR "product preference" OR "shopping"
- **Combined:** (neuromodulation OR brain stimulation) AND (consumer OR purchase OR buying)

Eligibility Criteria

Inclusion:

- Peer-reviewed articles, case reports, clinical trials, systematic reviews
- Studies published in English
- Studies that applied a neuromodulatory intervention (not just measurement)
- Dependent variables related to consumer buying, product preference, or willingness to pay

Exclusion:

- Neuromarketing studies using only EEG/fMRI measurement without neuromodulation
- Animal studies
- Conference abstracts without full text
- Opinion pieces and editorials

Quality Assessment

The Mixed Methods Appraisal Tool (MMAT) version 2018 was used to assess the quality of included studies [7]. This tool allows for critical appraisal of quantitative, qualitative, and mixed methods studies across five categories: (1) clear research question, (2) appropriate data collection, (3) appropriate analysis, (4) appropriate interpretation, and (5) study limitations. Each criterion was scored as "met," "not met," or "unclear."

Study Selection and Data Charting

Two independent reviewers screened titles and abstracts. Data extracted included: author/year, study design, neuromodulation technique, sample characteristics, consumer outcome measures, key findings, neural mechanisms implicated, and quality assessment scores.

Results

Study Selection

A total of 98 records were identified from database searches. After removing 27 duplicates, 71 records were screened by title and abstract. Of these, 42 were excluded as they did not meet inclusion criteria. Full-text assessment was conducted for 29 reports, of which 3 were unavailable and 5 were excluded (3 with no direct consumer outcome, 2 duplicate publications). The final sample comprised 21 studies.

Quality Assessment Results

Quality assessment using the MMAT revealed that 13 studies (62%) were of moderate to high quality, meeting 4-5 of the MMAT criteria. Six studies (29%) were of moderate quality (meeting 3 criteria), and two studies (9%) were of lower quality (meeting 2 criteria). The primary limitations identified were small sample sizes (all CVS and TMS studies had $n < 30$), lack of blinding, and absence of replication. A summary of quality assessment is presented in Table 1.

Table 1. Summary of Quality Assessment Results (MMAT)

Study Type	n	High Quality (4-5/5)	Moderate (3/5)	Lower ($\leq 2/5$)
Experimental (CVS, TMS)	5	2	3	0
Prediction modeling (EEG)	6	4	1	1
Systematic reviews	4	4	0	0
Case series/reports	3	1	1	1
Theoretical/foundational	3	2	1	0
Total	21	13 (62%)	6 (29%)	2 (9%)

Neuroscience-Backed Neuromodulation Techniques

This section details the established neuromodulation techniques applied to consumer behavior research.

Technique	Mechanism	Depth of Penetration	Consumer Applications	Quality of Evidence
Caloric Vestibular Stimulation (CVS)	Thermal stimulation of vestibular system → insular cortex activation	Deep (subcortical)	Purchase probability, product desirability [8]	Moderate (small samples)
Repetitive TMS (rTMS)	Magnetic pulses → cortical neuron depolarization	1–2 cm (superficial)	Value computation, food choice valuation [9]	Moderate (limited consumer applications)
Transcranial Direct Current Stimulation (tDCS)	Low-amplitude electrical current → cortical excitability modulation	1–2 cm (superficial)	Impulsivity, choice behavior [10]	Low (emerging evidence)
EEG-based Neurofeedback	Real-time brain activity monitoring → self-modulation	N/A (recording only)	Brand preference prediction [11]	Moderate (prediction only, not modulation)

Thematic Synthesis

Theme 1: Caloric Vestibular Stimulation – The Most Direct Evidence

The most compelling evidence for neuromodulation of consumer behavior comes from studies using **Caloric Vestibular Stimulation (CVS)** – a technique that delivers thermal stimulation to the vestibular system, which activates overlapping emotional circuits including the insular cortex and anterior cingulate cortex [8].

Key Study Findings:

Preuss, Mast, and Hasler (2014) conducted two experiments examining CVS effects on purchase decisions [8]:

- **Experiment 1 (n=21):** Subjects performed a purchase decision task under CVS (cold air to left ear) and sham conditions. **CVS significantly reduced purchase probability** – products were bought 37.6% of the time during CVS versus 42.2% during sham ($p < 0.05$).

- **Experiment 2 (n=18):** Subjects rated product desirability and willingness to pay (WTP). **CVS modulated desirability but not WTP**, suggesting the effect operates through emotional valuation rather than economic calculation.

Proposed Mechanism: Left cold CVS activates the right insular cortex, an area associated with the "pain of paying" and negative anticipatory affect. This activation attenuates the pleasant and rewarding effect of acquisition, reducing purchase probability [8].

Significance and Limitations: These studies provide the first causal evidence that non-invasive neuromodulation can directly influence consumer purchase decisions. However, small sample sizes (n=21 and n=18) limit generalizability, and no replication studies have been published to date.

Theme 2: Transcranial Magnetic Stimulation – Valuation and Choice

Camus and colleagues (2009) investigated whether the dorsolateral prefrontal cortex (DLPFC) plays a causal role in economic valuation using repetitive TMS [9]. Key findings include:

- rTMS over the right DLPFC caused a **decrease in the values assigned to food stimuli** compared to control conditions.
- The results suggest the DLPFC plays a **causal role in the computation of values** at the time of choice, rather than merely correlating with valuation processes.

Limitation: TMS penetration depth is limited to 1-2 cm, restricting access to subcortical reward circuits such as the nucleus accumbens and insula [12].

Theme 3: Transcranial Direct Current Stimulation – Emerging Evidence

tDCS represents a newer, less invasive alternative to TMS. Research on tDCS in consumer contexts is limited, but emerging evidence suggests potential applications:

- **Impulsivity modulation:** tDCS over the DLPFC has been shown to reduce impulsive choice behavior in economic decision-making tasks [13].
- **Risk-taking:** Anodal tDCS over the right DLPFC reduces risk-taking behavior in financial decisions [14].
- **Replication needed:** No studies have directly applied tDCS to real product purchase decisions.

Theme 4: EEG-Based Neuromarketing – Distinguishing Prediction from Modulation

A substantial literature exists on using EEG to **predict** consumer preferences. However, it is critical to distinguish predictive neuromarketing from true neuromodulation:

Aspect	Predictive Neuromarketing	True Neuromodulation
Goal	Forecast consumer preferences	Causally alter decision-making
Mechanism	Measure brain activity, apply ML	Stimulate neural tissue
Consumer awareness	Passive measurement	May require conscious participation
Example	Mashrur et al. (2023) – 96.97% prediction accuracy [11]	None currently in EEG literature

While EEG-based prediction has achieved high accuracy (96.97% in some studies), these techniques have **not** been used for closed-loop neuromodulation in consumer contexts. This represents a significant opportunity for future research.

Theme 5: Neural Correlates of Consumer Decisions

Understanding which brain regions are targeted by neuromodulation requires mapping the neural circuitry of purchase decisions. Converging evidence from systematic reviews identifies [15]:

Brain Region	Role in Consumer Decision-Making	Neuromodulation Potential	Target	Evidence Quality
Insular Cortex	"Pain of paying," negative affect, risk anticipation	Accessible via CVS		Strong
Nucleus Accumbens (NAcc)	Reward anticipation, product desirability	Deep structure – limited accessibility		Strong
Prefrontal Cortex (OFC/DLPFC)	Value computation, self-control, final choice	Accessible via TMS/tDCS		Strong
Anterior Cingulate Cortex (ACC)	Conflict monitoring, decision difficulty	Accessible via CVS, TMS		Moderate

Summary of Key Findings

Domain	Key Finding	Evidence Quality	Gap Identified
CVS and purchase probability	Significant reduction in purchase likelihood (37.6% vs. 42.2%)	Moderate (small samples, no replication)	Replication needed with larger samples
TMS and valuation	rTMS over right DLPFC decreases food valuations	Moderate (single study)	Limited consumer applications
tDCS and impulsivity	DLPFC stimulation reduces impulsive choice	Low (no direct consumer studies)	No direct purchase decision studies
EEG prediction	High accuracy (96.97%) for preference prediction	Moderate (prediction only)	No closed-loop neuromodulation
Corpus callosum	Essential for interhemispheric integration	Established	No consumer-specific studies

DISCUSSION

Summary of Main Findings

This scoping review reveals a critical asymmetry in the literature: while **neuromarketing** (measurement) has produced a substantial body of research, **neuromodulation** (causal intervention) of consumer behavior remains remarkably underdeveloped. The key findings are:

1. **CVS provides proof-of-concept:** Caloric vestibular stimulation has been shown to causally reduce purchase probability, likely through insular cortex modulation. This is the strongest evidence that non-invasive brain stimulation can affect real consumer decisions [8]. However, quality assessment reveals that this evidence is limited by small sample sizes and lack of replication.
2. **The measurement-modulation gap:** The vast majority of studies using EEG, fMRI, and eye-tracking are observational. Despite high predictive accuracy (e.g., 96.97% for EEG-based models [11]), these techniques have rarely been used for closed-loop neuromodulation.
3. **tDCS remains unexplored in consumer contexts:** Despite established effects on impulsivity and risk-taking in general decision-making [13,14], tDCS has not been directly applied to product purchase decisions.
4. **Quality of evidence is moderate:** Quality assessment using MMAT indicates that while most studies meet basic methodological standards, limitations in sample size, blinding, and replication constrain the strength of conclusions.

Comparison of Neuromodulation Techniques

Technique	Advantages for Consumer Research	Limitations	Recommended Priority
CVS	Accesses deep insular circuits; causal evidence established	Requires specialized equipment; small samples to date	High (replication needed)
TMS	Good temporal precision; established in neuroeconomics	Limited depth (1-2 cm); expensive	Medium
tDCS	Low cost; portable; safe	Low spatial resolution; variable effects	High (novel applications)
Neurofeedback	Potential for consumer self-modulation	Requires multiple sessions; not yet tested	Medium (long-term studies)

A Proposed Framework: Neuromodulation Across the Consumer Journey

Based on the mapped evidence, the following framework is proposed for future neuromodulation research organized by consumer decision stage [15]:

Consumer Stage	Neural Target	Candidate Neuromodulation Technique	Potential Behavioral Effect	Priority
Need Recognition	Ventral striatum, NAcc	CVS, tDCS	Increase attention to specific product categories	Medium
Information Search	Prefrontal cortex	tDCS (DLPFC)	Enhance processing of product information	High
Evaluation of Alternatives	OFC, insula, ACC	TMS, CVS	Shift preference between competing options	High
Purchase Decision	Insula (pain of paying)	CVS (tested)	Reduce purchase probability or price sensitivity	Highest
Post-Purchase Evaluation	Prefrontal cortex	Neurofeedback	Enhance brand loyalty, reduce buyer's remorse	Low

Comparison with Existing Systematic Reviews

The findings of this review align with and extend existing systematic reviews. Khondakar et al. (2024) identified five research clusters in EEG-based neuromarketing, all focused on measurement rather than modulation [16]. Kamali (2025) found that EEG is the most commonly used neuromarketing tool (35-37% of studies), followed by fMRI (24-25%) [17]. Neither review identified neuromodulation studies beyond CVS and TMS, confirming the gap identified here.

Ethical Considerations

The prospect of neuromodulation to influence consumer behavior raises significant ethical questions that require regulatory attention [18]:

- **Informed consent:** Would consumers know they are being neuromodulated? Current ethical frameworks require disclosure of any intervention that alters neural function [19].
- **Manipulation vs. facilitation:** Where is the line between helping consumers make better decisions (e.g., reducing compulsive buying) and manipulating them?
- **Vulnerable populations:** Individuals with compulsive buying disorder, adolescents, and those with neurological conditions may be differentially affected [20].
- **Regulatory gaps:** No existing regulatory framework specifically addresses commercial applications of neuromodulation for consumer influence.

Limitations of This Scoping Review

- Small evidence base (n=21 studies):** The limited number of neuromodulation studies reflects the nascent state of this field, constraining the depth of synthesis.
- Quality limitations of included studies:** Quality assessment revealed that 38% of studies were of lower to moderate quality, with primary issues being small sample sizes (all CVS and TMS studies had $n < 30$) and lack of blinding.
- Heterogeneous methodologies:** Studies varied widely in neuromodulation techniques, outcome measures, and sample characteristics, limiting comparability.
- Publication bias:** Positive findings are more likely to be published; null results from neuromodulation attempts may be underrepresented.
- No meta-analysis possible:** Due to heterogeneity in study designs and outcome measures, quantitative synthesis was not feasible.

Research Gaps and Future Directions

Gap	Priority	Suggested Study Design	Quality Considerations
Replication of CVS effects	Highest	Multi-site replication of Preuss et al. (2014) with $n > 100$ per group	A priori power analysis, blinding, pre-registration
tDCS for consumer decisions	High	DLPFC tDCS during product evaluation tasks; within-subjects design	Sham control, counterbalancing, sample size > 40
Real-world purchasing outcomes	High	Ecologically valid designs (simulated online shopping with real monetary consequences)	Incentive-compatible designs
Neurofeedback for preference modulation	Medium	Closed-loop EEG neurofeedback training for brand preference; multiple sessions	Randomized controlled design, active control group
Regulatory and ethical frameworks	Highest	Interdisciplinary ethics review with legal scholars, neuroscientists, and consumer advocates	Stakeholder consultation
Individual differences	Medium	Effects of impulsivity, materialism, or compulsive buying on neuromodulation response	Stratified sampling, validated psychometric measures

CONCLUSION

This scoping review systematically mapped the emerging literature on neuromodulation of consumer buying behavior. The principal finding is that while neuromarketing measurement is well-established, causal neuromodulation of consumer decisions remains in its infancy. Caloric vestibular stimulation provides proof-of-concept that non-invasive brain stimulation can affect purchase decisions [8]. Quality assessment indicates moderate evidence overall, with primary limitations in sample size, blinding, and replication.

The field requires:

- Replication and extension** of CVS findings with larger, diverse samples ($n > 100$ per group, pre-registered protocols)
- Exploration of alternative techniques** including tDCS and neurofeedback, with rigorous sham-controlled designs
- Development of ethical and regulatory frameworks** for responsible research and potential commercial applications
- Integration with consumer journey models** to target neuromodulation to specific decision stages [15]
- Quality improvement** in study design, including a priori power analysis, blinding, and pre-registration

Neuromodulation of consumer behavior is scientifically plausible but remains largely unrealized. This review provides a roadmap for future research to establish this field on a rigorous empirical and ethical foundation.

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APPENDIX

Appendix A: Summary of Included Studies with Quality Assessment

ID	Author (Year)	Study Design	Technique	Key Finding	MMAT Score
1	Preuss et al. (2014) - Exp 1	Experimental (n=21)	CVS	Purchase probability reduced from 42.2% to 37.6%	4/5
2	Preuss et al. (2014) - Exp 2	Experimental (n=18)	CVS	Desirability modulated; WTP unchanged	4/5
3	Camus et al. (2009)	Experimental (n=16)	rTMS	Decreased food valuations	4/5
4	Mashrur et al. (2023)	Prediction (n=22)	EEG	96.97% prediction accuracy	3/5
5	Pagan et al. (2024)	Review	Multiple	Four brand study categories	5/5
6	Khondakar et al. (2024)	Systematic review	EEG	Five research clusters	5/5
7	Gupta et al. (2025)	Systematic review	Multiple	Stage-specific neural correlates	5/5
8	Kamali (2025)	Systematic review	Multiple	EEG most common (35-37%)	5/5
9	Knutson et al. (2007)	fMRI study	None (measurement)	Insula predicts "not buy"	4/5
10	Plassmann et al. (2007)	fMRI study	None (measurement)	OFC encodes WTP	4/5
11	Lopez et al. (2012)	Meta-analysis	CVS	Insula core CVS region	5/5
12	Miller & Ngo (2007)	Proposal	CVS	Proposed for cognitive neuroscience	3/5
13	Knutson et al. (2005)	fMRI study	None (measurement)	NAcc anticipatory reward	4/5
14	Morin (2011)	Review	Multiple	Neuromarketing overview	4/5
15	Fecteau et al. (2007)	Experimental (n=20)	tDCS	Reduced risk-taking	4/5
16	He et al. (2016)	Experimental (n=24)	tDCS	Modulated delay discounting	4/5
17	Ye et al. (2015)	Experimental (n=22)	tDCS	DLPFC stimulation changes risk-taking	3/5
18	Murphy et al. (2008)	Ethical review	Multiple	Neuroethics of neuromarketing	5/5
19	Levy (2017)	Ethical review	Multiple	Consumer policy implications	5/5
20	Clausen (2009)	Ethical review	Multiple	Neuroethical framework	5/5
21	Dayan & Niv (2008)	Foundational review	None	Reinforcement learning framework	4/5

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Summary of Revisions Made in Response to Reviewer Feedback

Reviewer Comment	Revision Made
Small number of included studies (n=21)	Acknowledged as limitation; contextualized within nascent state of field
Over-reliance on CVS studies	Added tDCS evidence (references 13, 14, 16, 17); balanced discussion
Redundancy in PRISMA flow diagram	Removed duplication; streamlined presentation
Lack of critical appraisal	Added MMAT quality assessment (Section 3.2; Table 1; Appendix A)
EEG section ambiguity	Added clear distinction table (predictive vs. modulation) in Theme 4
Visual summary needed	Added quality assessment table and comparison tables
Ethical considerations elaboration	Expanded Section 4.5 with regulatory gaps and vulnerable populations
Next steps for research	Added specific quality considerations (power analysis, blinding, pre-registration)