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Heart rate variability in marketing research: A systematic review and methodological perspectives

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Abstract

Heart rate variability is a promising physiological measurement that accesses psychophysiological variations in response to a marketing stimulus. While its application spans diverse fields, there is a limited understanding of the usability and interpretation of heart rate variability in marketing research. Therefore, this hybrid literature review provides an overview of the emerging use of heart rate variability in marketing research, along with essential methodological considerations. In this context, we blend marketing mix framework with stimulus-organism-response theory, segregating the use of heart rate variability in various marketing research contexts. We follow the preferred reporting items for systematic reviews and meta-analyses (PRISMA) framework to reflect on 33 records obtained from six databases. Our findings suggest that 42% of studies used heart rate variability to investigate promotion-related topics. Overall, heart rate variability is mostly used in combination with Galvanic skin response (48%). Further, 39% of studies used non-portable systems for data collection. Last, using the theory characteristics methodology (TCM) framework, we identified six research avenues: (1) affective, cognitive, and sensorial constructs; (2) personality, thinking style, and demographics; (3) product experience; (4) advertising and branding; (5) correlation with immersive technologies; and (6) triangulation with other neurophysiological tools.

KEYWORDS

bibliometric analysis, biometric, consumer neuroscience, heart rate variability, marketing research, systematic review

1 | INTRODUCTION

Advances in consumer neuroscience research in the last two decades have allowed marketing researchers to effectively utilize psychophysiological tools to quantify the affective and cognitive processes of consumers that are triggered by marketing stimuli (Bell et al., 2018; Casado-Aranda & Sanchez-Fernandez, 2022; Mcaleer et al., 2022). Consumer neuroscience research applies neuroscience and psychological methods to processes that underpin consumer buying behavior (Karmarkar & Plassmann, 2019; Lee et al., 2018). Alvino et al. (2020) proposed a framework that classifies consumer neuroscience tools into three categories based on how responses to marketing stimuli are measured: (a) behavioral tools that record conscious reactions (e.g., selfreports, reaction time); (b) physiological tools that measure voluntary or involuntary physiological changes (e.g., Galvanic skin response, heart rate variability);

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and (c) neurophysiological tools that assess brain activations (e.g., electroencephalogram, functional magnetic resonance imaging). In this context, heart rate variability series, defined as the instantaneous variation of time intervals between adjacent heartbeats, is a promising tool for identifying and evaluating consumer psychophysiological responses to marketing stimuli, given its cost-effectiveness and easy-to-acquire data capabilities. Additionally, advancements in wearable and portable electrocardiogram (ECG) devices (e.g., fitness monitors, Apple watches) provide continuous (temporally precise over seconds, minutes, and hours), ecological (real-world conditions), and scalable collections of cardiac activity data in different contexts (Nelson et al., 2020), broadening opportunities for marketing researchers to improve real-time consumer experiences (Orazi & Nyilasy, 2019).

Although there is debate about the precise definition of emotion, Kleinginna and Kleinginna (1981) posited that emotion can be divided into three components: subjective experience, expressive response, and physiological arousal. Because emotional states and physiological arousal are inextricably related (Herman et al., 2018), the employment of physiological, noninvasive measurements has become prevalent in marketing research (Casado-Aranda & Sanchez-Fernandez, 2022). In this sense, cardiac activity is not restricted to physiological arousal but is also linked to cognitive and affective processes (Candia-Rivera et al., 2022; Massaro & Pecchia, 2019; Poels & Dewitte, 2006; Verhulst et al., 2019). The use of heart rate variability recordings can improve two major constraints of traditional marketing methodologies by providing: (1) ease of continuous measurement for unconscious level processing of stimuli in a naturalistic setting; and (2) quantitative and robust physiological measurements related to consumers' affective and cognitive responses to triangulate with selfreports (Bell et al., 2018); however, there is a lack of standardization in marketing research design and the data pipeline.

With this in mind, this systematic literature review aims to achieve the following research goals: (1) to promote the use of heart variability tools in marketing research by providing methodological guidelines, and (2) to draw out major strands of potential research. We also highlight two major research questions: (RQ1) What are the emerging marketing research topics investigated using heart rate variability? and (RQ2) What heart rate variability measures are commonly used in marketing research? As a result, and based on the theory characteristics methodology (TCM) Framework, this study identifies six research avenues for marketing research using heart rate variability. Likewise, this study provides guidelines for conducting heart rate variability studies.

In Section 2, we outline the theoretical basis for heart rate variability and provide background on the marketing mix and stimulus-organism-response (SOR) framework. In Section 3, we use the preferred reporting items for systematic reviews and meta-analyses (PRISMA) framework to identify relevant articles. In Section 4, we present the findings and discuss potential developments in marketing research. This study adapts a hybrid review methodology (see Paul and Criado [2020] for the classification of systematic review articles), wherein we follow a descriptive and bibliometric-oriented analysis of the records and follow the TCM approach to present future research avenues. Section 5 provides guidelines for planning heart rate variability-based study for marketing research. Section 6 summarizes the study and highlights the limitations.

2 | THEORETICAL BACKGROUND

First, it is important to distinguish between "heart rate" and "heart rate variability" measurements. Heart rate variability is a time series, also referred to as R-R interval series or interbeat interval series, drawn from the timing between successive heartbeats, identified through R-peaks in the ECG. Heart rate refers to the number of heartbeats in a specific time interval and is a feature that can be derived from heart rate variability series analysis.

2.1 | Fundamentals of heart rate variability

Heart rate variability series is the time-resolved signal that reflects changes in cardiovascular activity caused by the synergistic action of its two constitutive branches: the sympathetic nervous system and the parasympathetic nervous system (Acharya et al., 2006; Shaffer & Ginsberg, 2017). While sympathetic nervous system plays a dominant role in the body's fight-or-flight response, which may increase heart rate, the parasympathetic system activity is associated with a rest-and-digest state and may decrease heart rate (see Figure 1). Their joint activity maintains a balanced state in the body (Pham et al., 2021) and contributes to the regulation of heart rate over time, thus defining heart rate variability at each moment in time. Sympathetic nervous system may exhibit physiological arousal through increased heart rate and blood pressure, while the parasympathetic one may decrease physiological arousal, that is, heart rate deceleration via the vagus nerve. Importantly, concurrent sympathetic and parasympathetic nervous system heartbeat regulation activity may result in nonlinear dynamics (Sunagawa et al., 1998). The parasympathetically (vagally) mediated heart rate has faster beat-to-beat variations than the sympathetically mediated heart rate, which has slower changes in beat-to-beat variations.

The autonomic nervous system continuously interacts with the central nervous system via bottom-up or top-down communications (Candia-Rivera et al., 2022; Owens et al., 2017). Specific brain regions, such as the prefrontal cortex, amygdala, and medulla oblongata, considered part of the central-autonomic network (Silvani et al., 2016; Valenza et al., 2019), are involved in decision-making, threat response, and emotional processing. In this context, the heart rate variability series may be considered as a proxy measurement of brain–heart interplay (Candia-Rivera et al., 2022).

2.1.1 | Data collection

ECGs are the gold standard for retrieving heart rate variability series; alternatively, pulse rate variability may be used as a heart rate variability surrogate series. An ECG captures rhythmic changes in the heart via electrical impulses, while the pulse represents volumetric change in

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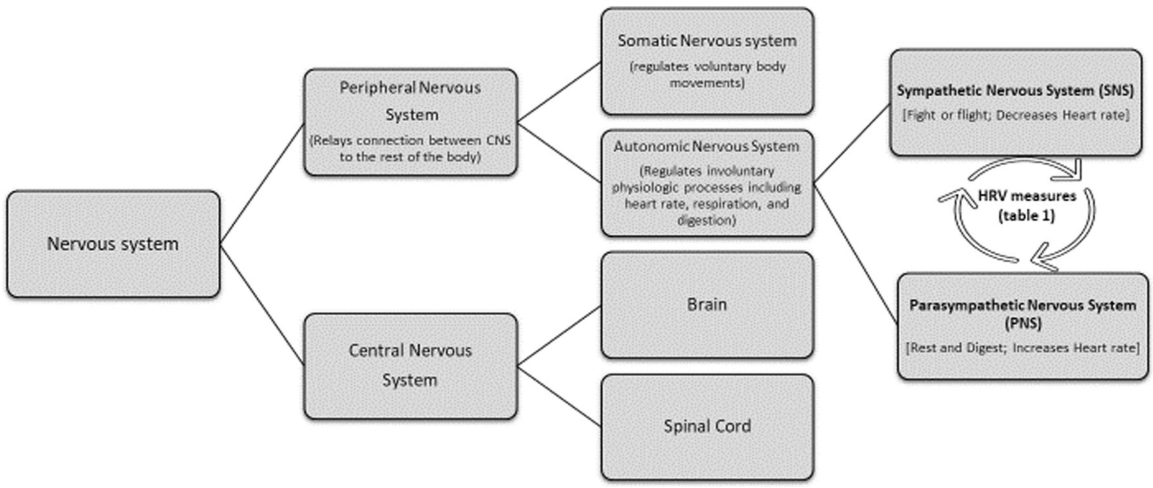

FIGURE 1 Schematic and exemplificative diagram of the nervous system and its relation to the sympathetic and parasympathetic branches. Source: Author's own elaboration.

blood profusion (Nelson et al., 2020). An ECG system acquires electric potentials generated by the rhythmic movement of the heart due to depolarization, captured via electrodes placed on the chest. Pulse rate variability obtains heart rate variability information from pulse wave signals (time variations in pulse-to-pulse cycles) and is usually obtained through photoplethysmograms (i.e., an optical technique) from various locations on the body, such as the fingers, arms, or wrists (Ishaque et al., 2021). Photoplethysmography is a low-cost, noninvasive tool for capturing changes in autonomic activity. The higher portability, lower cost, and noninvasive qualities of pulse rate variability make it easier to implement in marketing studies, but at the cost of a sensible decrease in signal quality.

Heart rate variability is a highly nonstationary, complex signal that expresses temporal variation in adjacent heartbeat intervals (Acharya et al., 2006; Catrambone et al., 2019). To ensure signal robustness, the data analysis pipeline requires preprocessing (Bulagang et al., 2020) to account for missing data detection, segmentation of intervals of interest, artifacts (missing beats and arrhythmias), and noise rejection. Preprocessing includes filtering, which deletes inapplicable frequency components, thereby increasing the defined signal-to-noise ratio. To obtain the heart rate variability series, the amount of time between heartbeats (i.e., R-peaks) (Peltola, 2012) should be measured in the ECG, which allows for the RR intervals (heart rate) to be estimated and, therefore, the heart rate variability series. The R-peak usually has the highest value in the ECG series. It is recommended that at least 15 min of resting state be recorded before beginning an experiment to normalize the initial internal state of the subject (Catai et al., 2020), although such timing is subjective and contingent upon experimental conditions.

2.1.2 | Analysis and measures

One of the most widely used algorithms to identify R-peaks is from Pan and Tompkins (1985). There is a diverse amount of software providing similar outputs available for analyzing the heart rate variability (see Singh et al. 2015). Data analysis quality is heavily dependent on data acquisition procedures (see detailed checklists by Catai et al., 2020).

Heart rate variability analysis can be performed in different domains, including time, frequency, and nonlinear, as reported in Table 1. Time domain metrics capture periods of various lengths, with difference-based indices that are indicative of robust, short-term variations (Pham et al., 2021), while other metrics, mainly those influenced by PNS activity, are better suited for short-term analysis (Shaffer & Ginsberg, 2017). Frequency domain metrics are derived from spectral analysis, whereby the heart rate variability series is decomposed from fundamental oscillations into three main components: very low frequency (VLF), low frequency (LF), and high frequency (HF). Based on recent autonomic dynamics evidence, the LF power band is considered a marker of sympathovagal activity (Shaffer & Ginsberg, 2017), and HF power a marker of vagal activity, as long as the respiratory frequency is in the same frequencies (Thomas et al., 2019). It has been argued that the ratio between LF and HF power (LF/HF) is indicative of sympathovagal balance; however, the scientific community has only debated the specificity of these bands separately. Employing several derived features is recommended to ensure the robustness of the analysis. Since frequencies are dependent on the length of the recording window, it is advisable to report LF and HF power in both normalized and absolute forms. Nonlinear indices quantify the predictability underlying cardiovascular regulation (Ishaque et al., 2021). Entropy-based indices measure the predictability (or regularity) of a signal to discern randomness and complexity. Lower entropy (lower irregularity) indicates more predictable cardiac variability dynamics (Peltola, 2012). The correlational dimension (CD) calculates the regression line from the log-log representation; the higher the CD, the greater the heart rate variability complexity (Ishaque et al., 2021).

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TABLE 1 Summary of common heart rate variability measures and their functional descriptions

Heart rate variability indices	Unit of analysis	Functional description
Time domain (linear domain)		
Heart rate (HR)	Beats per minute (bpm)	Number of R-peaks per minute. The variability in the HR provides information about the functioning of nervous control on heart activity and the heart's ability to respond.
Standard deviation of RR intervals (SDRR)	Milliseconds (ms)	Mean square difference between each RR interval and their mean, normalized by the number of RR intervals in the given time window. Mediated by cardiac vagal activity. Alternatively, the standard deviation of NN intervals (SDNN) can also be used.
Square root of the mean squared differences between successive RR intervals (RMSSD)	ms	Reflects beat-to-beat variance in heart periods. Correlated with HF power and pNN50. Mediated by cardiac vagal activity.
Percentage of adjacent RR intervals with a difference of more than 50 ms (pNN50)	Percentage (%)	Usually correlated with the RMSSD and HF power. Mediated by cardiac vagal activity.
Triangular index		Total number of RR intervals divided by the number of RR intervals in its modal bin in the density distribution histogram. Highly correlated with SDRR. Obtained as a graphical representation (histogram, scatter plot) of N–N intervals.
Frequency domain (linear domain)		
Total power	ms^2	Spectral power in the <0.4 Hz band. Modulated by sympathetic, vagal, and baroreceptor activity.
Low frequency (LF) peak	Hz	Frequency associated with the magnitude peak in the LF band (0.04–0.14 Hz). Modulated by sympathetic, vagal, and baroreceptor activity.
Very low frequency (VLF) band	ms^2	Absolute power of the VLF band (0.003–0.04 Hz). A not-specific measure of autonomic activity and health condition.
LF band	ms^2	Absolute power calculated in the LF band (0.04–0.14 Hz). Modulated by sympathetic, vagal, and baroreceptor activity.
High frequency (HF) band	ms^2	Absolute power calculated in the HF band (0.14–0.4 Hz). Modulated by cardiac vagal activity if the respiratory frequency is within 0.14–0.4 Hz.
HF peak	Hz	Frequency associated with the magnitude peak in the HF band. Modulated by cardiac vagal activity if the respiratory frequency is within 0.14–0.4 Hz.
LF/HF		Ratio between LF and HF band powers. Modulated by sympathetic, vagal, and baroreceptor activity.
Nonlinear domain		
Approximate entropy (ApEN); Sample entropy (SampEn); Shannon entropy (ShEN)		Quantification of heartbeat dynamics regularity and predictability. The lower the entropy value, the more predictable and regular the signal. Likely to be modulated by cardiac vagal activity.
Correlational dimension (CD)		Measure of fractal dimension. Proportional to the probability that two arbitrary points on the orbit are closer together than r. Likely to be modulated by cardiac vagal activity. As CD values increases, the cardiac system reflects better adaptive responses to external stimuli.

Note: Adapted from Pham et al. (2021) and Shaffer and Ginsberg (2017).

2.2 | Heart rate variability and marketing research

Marketing actions elicit neural and physiological responses. For our review, we integrated the marketing mix framework with the SOR framework. Our conceptual framework (Figure 2) clearly illustrates marketing mix as antecedental to consumer psychophysiological processing, which results in behavioral output. Prior studies have utilized the classic 4Ps framework (Waterschoot & Van den Bulte 1992), which includes four dimensions—product, price, promotion, and place—successfully highlighting the contribution of physiological and neurophysiological tools in consumer marketing (see Bazzani et al., 2020, for a review). These dimensions help managers craft products and campaigns that suit consumer needs. Previous literature reviews have utilized the SOR framework to examine underlying

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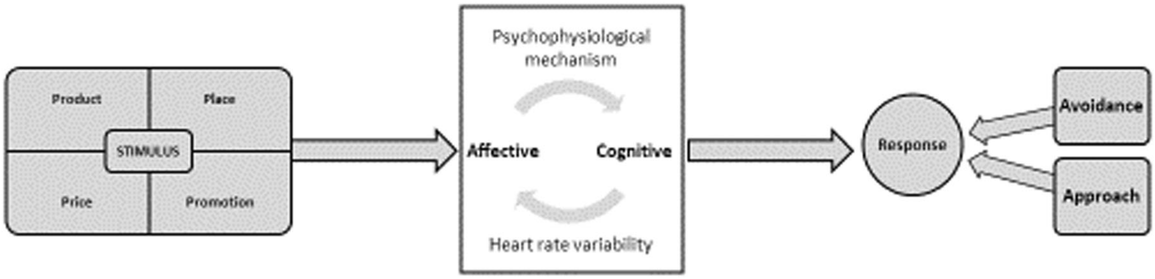

FIGURE 2 Conceptual framework formed by blending marketing mix and stimulus-organism-response theories

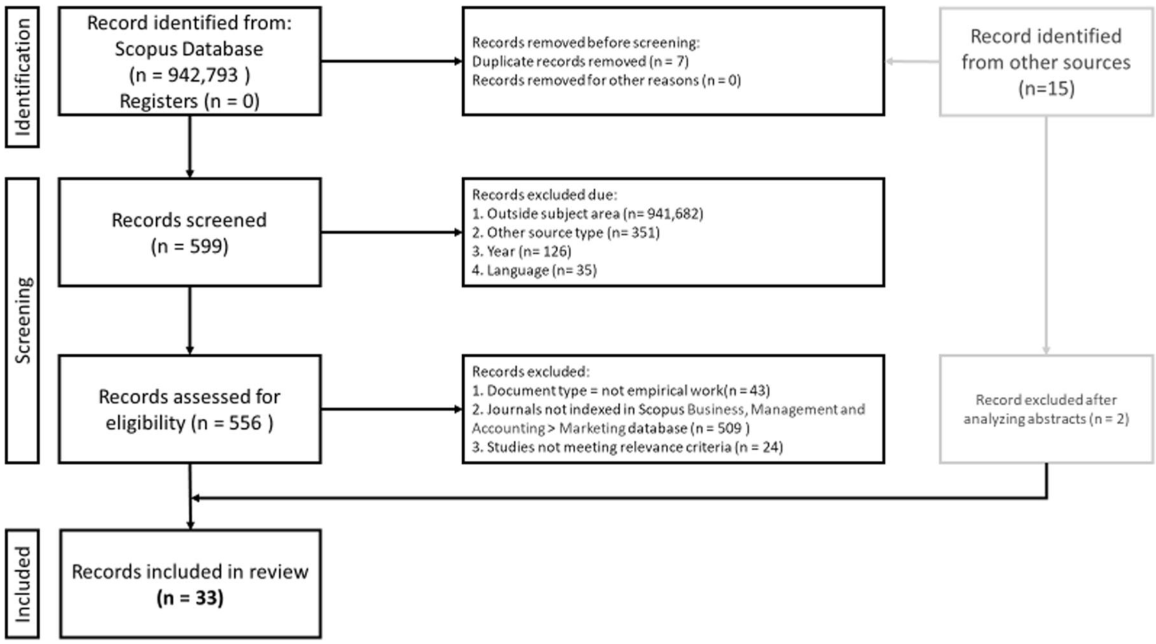

FIGURE 3 Preferred reporting items for systematic reviews and meta-analyses flow chart indicating each step for identifying articles

consumer physiological mechanisms (Xiong & Zuo, 2020). Mehrabian and Russell's (1974) SOR framework highlights the stimulus component as an external (environmental) factor, while the organism component reflects the consumer's affective or cognitive intermediate processes as a consequence of being exposed to stimulus. The response component reflects approach or avoidance behavior, that is, shopping behavior outcomes in response to the stimulus (Mehrabian & Russell, 1974). This unique framework will help navigate the literature and facilitate an understanding of the influence of marketing stimuli on consumer responses through heart rate variability metrics.

3 | METHODS

To analyze how heart rate variability has been used in marketing research, we adapted the guidelines as specified in PRISMA (see Page et al., 2021). Figure 3 shows a PRISMA flowchart summarizing the review process.

3.1 | Search strategy

Our primary source for this study was Scopus, since it has the broadest range of indexed academic journals and has been used in previous marketing studies to develop review articles (Mariani et al., 2022). Our secondary electronic databases included web of science (WOS), Frontiers, PubMed, PLoS ONE, and a quick crosscheck with Google Scholar. We then ran a query ("heart AND rate" OR "electrocardiogra*" OR "HRV" OR "heart AND rate AND variability") in our primary database with search fields related to "article title," "abstract," and "keywords." We considered work that was published up until May 05, 2022. The inclusion and exclusion criteria were set before proceeding to further stages.

3.2 | Screening procedures

For the exclusion criteria, articles outside of the areas of business, management, and accounting were removed. Articles

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other than those in journals, that predated 2000–2022, or were published in any language other than English were also excluded. Among the inclusion criteria, documents categorized as articles were retained, and only the source titles that corresponded with the Scopus database for marketing journals within the business, management, and accounting sections (Supporting Information: Appendix A). Source titles and corresponding articles that were removed at this stage can be viewed in Supporting Information: Appendix C. After a manual, in-depth screening of the remaining articles, only those that passed our relevance criteria were included in the results. The relevance criteria indicate (a) studies that measure consumer affective- or cognitive-relevant constructs, and (b) studies that report one or more empirical results using heart rate variability series, either as a core or complementary measure. Documents that didn't pass this stage can be viewed in Supporting Information: Appendix C. To reduce the probability of bias in developing the final corpus, these criteria were individually checked by two authors. The primary author established the inclusion and exclusion criteria for extracting appropriate records, while the secondary author established the relevance criteria. The final list of records was developed after both authors independently scanned each record for their suitability and resolved doubts.

3.3 | Secondary databases

In conjunction with the primary database, a similar search resulted in 15 articles from WOS ($n = 7$) (see Supporting Information: Appendix F), Frontiers ($n = 2$), PubMed ($n = 0$), PLoS ONE ($n = 3$), and the crosscheck with Google Scholar ($n = 3$). The results obtained from WOS were already part of the Scopus data set and were excluded to avoid duplication. We read the abstracts of the remaining eight articles and found two ineligible for inclusion in the final corpus.

3.4 | Record selection

The Scopus database yielded 27 articles, and the secondary databases yielded six additional papers; the final corpus included 33 articles. Next, we retrieved the data set, which included article titles, author information, countries and regions, publication details (i.e., total number of publications, total and average citations), all keywords, and journal sources. Table 2 presents the articles.

4 | RESULTS AND DISCUSSIONS

This section presents the key findings through descriptive analyses of the records, followed by a bibliometric analysis. This is followed by commentary on prospective research lines and general considerations for executing studies that use heart rate variability.

4.1 | Descriptive analysis

In addition to the key records findings using our framework, we also provide details about the underlying theories, the research design, the various types of devices to record heart rate variability and commonly used consumer neuroscience tools with heart rate variability.

4.1.1 | Marketing mix

Table 2 divides the articles based on four marketing mix themes and provides an overview of sample demographics, heart rate variability measures used, and the key findings of each article relevant to RQ1 and RQ2. Heart rate variability has been used the most for studying promotion- and product-related aspects of the marketing mix (43% and 27%, respectively). Aspects related to place (15%) and price (3%) were not of interest.

4.1.2 | Common theoretical lens

Since the literature on the use of heart rate variability in marketing research is assorted, the records were divided based on two broad theoretical lenses—cognitive and affect-based (see Supporting Information: Appendix D). Affect-based theories were used as underlying mechanisms in 51% of studies, and only 27% used a cognitive-based theory. The limited capacity model of motivated mediated message processing (LC4MP) was a commonly used theory in 12% of the articles. LC4MP assumes that consumers have limited cognitive processing capacity to encode, store, and retrieve. This theory proposes that cognitive resources can process media messages automatically (from the environment) or through a controlled processing mechanism (conscious effort) (Lang, 2000).

4.1.3 | Research designs

Out of 33 empirical research articles, 52% used a within-subject design when using heart rate variability as a physiological tool (see Table 2). A between-subject design was used by 42%, and only 6% of studies used a mixed-subject design. Among these designs, between-subject provides easier setup and less risk of biasing the participants; within-subject requires lower sample sizes and offers a greater chance of capturing true differences in conditions; and mixed-subject provides greater statistical power in marketing research (Viglia et al., 2021).

4.1.4 | Common heart rate measurements

Out of the 33 articles, approximately 85% of the articles have used heart rate (or heart rate range) as the measurement

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TABLE 2 Records categorized according to the 4P marketing mix scheme

Article	Sampling	Design	Measure	Findings
Promotion				
Rodero and Potter (2021)	52 (29 females) Age (19–32)	Within subject	Heart rate (HR)	Messages in commercials with moderate emphasis (vs. no emphasis) improved consumer cognitive processing.
Martinez-Levy et al. (2022)	72 (36 males) Age (*M* = 37.5; SD = 10.8)	Between subject	HR	Lower emotional reaction observed in the closing section of second version of the spot compared to the first version.
Breuer et al. (2021)	11 (9 males) Age (18–32)	Within subject	HR	Sport spectator arousal decreases when outcome uncertainty is lowered; arousal increases when a winning game is close to ending.
So et al. (2021)	21 (12 females) Age (16–59; *M* = 38.09, SD = 14.02)	Between subject	High frequency (HF) band, Low frequency (LF) band, Very low frequency (VLF) band, LF/HF ratio	Heart rate variability dependent on the genre. High or low arousal content derived from previous heart rate variability is more engaging.
Sung et al. (2021)	125 (70 females) Age (M = 21.26, SD = 3.96)	Between subject	HR	Greater arousal and engagement for non-luxury versus luxury brand stories. Heart rate significantly decelerated in non-luxury versus luxury conditions.
Bellman et al. (2019)	1040 (530 females) Age (18–83)	Within subject	HR	Heart rate was significantly negatively correlated with fixation duration (attention).
Clark et al. (2018)	144 (72 females) Age (*M* = 32.44, SD = 11.48)	Between subject	Root of the mean squared differences (RMSSD)	Nonsignificant results between in-stream autoplay and click-to-play conditions.
Guixeres et al. (2017)	35 (20 males) Age (*M* = 25, SD = 5)	Within subject	Heart rate, RMSSD, pNN50, LF peak, LF band, HF band, HF peak, LF: HF ratio, total power, ApEN, SampEn, ShEN	SD2 Poincare index significantly different in ad recall versus no ad recall conditions. Similarly, LF band was significantly different for ad preference versus ad nonpreference groups.
Sung et al. (2016)	40 (20 males) Age (*M* = 20.12, SD = 3.14)	Within subject	HR	Cardiac deceleration evoked by advertisements with novel cues, in contrast to original advertisements of identical products.
Christoforou et al. (2015)	16 (11 females) Age (*M* = 22)	Within subject	RMSSD	Moderate negative relationship between RMSSD and divergence of eye gaze patterns while watching narrative-based video.
Venkatraman et al. (2015)	29 (11 females) Age (*M* = 33; SD = 10)	Within subject	LF band, HF band	Cardiac deceleration correlated with ad preference, ad recognition, and change in purchase intent.
Ha-Brookshire and Bhaduri (2014)	67 (47 females) Age (*M* = 34.36)	Within subject	HR	Heart rate deceleration is greater when messages are framed as malevolent versus benevolent.
Bellman et al. (2013)	64 (33 males) Age (19–75)	Mixed subject	HR	Web browsing ad relevance received more attention for low-involvement product commercials compared to high-involvement product commercials.
Bos et al. (2013)	35 (12 males) Age (18–25; *M*= 20.6)	Within subject	HR	No significant differences observed in HR between negative, neutral, and erotic film clips.

(Continues)

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TABLE 2 (Continued)

Article	Sampling	Design	Measure	Findings
Product				
Küster et al. (2021)	100 (54 females) Age (M = 21.49, SD = 2.46)	Between subject	HR	RR interval (HR) significantly differs based on product choice.
Simmonds et al. (2020)	133 Age (M = 46)	Mixed subject	Interbeat interval	Multisensory (audiovisual) cues elicit heart rate acceleration.
Mas et al. (2020)	49 (36 females) Age (M = 19.14, SD = 1.9)	Within subject	HR	Heart rate decreases when long sonic logos are slow-paced.
Noseworthy et al. (2014)	290 (163 males) Age (M = 25.2)	Between subject	HR	Fluctuating arousal varies the severity of negative (anxiety) or positive (curiosity) emotion, which alters product evaluations.
Maxian et al. (2013)	52 (37 females) Age (M = 21)	Within subject	HR	Viewing more loved brands led to cardiac deceleration.
Gangadharbatla et al. (2013)	60 (44 females) Age (M = 20.2)	Between subject	HR	Insignificant support for billboard recognition altering heart rate.
Mehta et al. (2012)	95 (60 females)	Between subject	HR	A moderate level of noise (70 dB) increases processing fluency and construal processing, enhancing performance on creative tasks.
Walla et al. (2011)	21 (14 females) Age (M = 28.14, SD = 6.29)	Between subject	HR	Significant reduction in heart rate when liked (vs. disliked) brand names are shown.
Hernandez and Minor (2011)	30 (17 female) Age (M = 34.17)	Within subject	HR	Arousal (HR) levels inversely related to brand recall scores but not recognition scores.
Place				
Luangrath et al. (2022)	144 (94 males)	Within subject	HR	Vicarious haptic effect enabled ownership and product evaluation for individuals reporting an elevation in heart rate in virtual reality retail store.
Hariharan et al. (2016)	37 (27 male)	Within subject	HR	Auction dynamics moderated relationship between emotional arousal (HR) and bid deviation.
M. T. P. Adam et al. (2015)	240 (182 males) Age (M = 22.09)	Within subject	HR (study 1)	Time pressure and social competition significantly and positively influenced arousal levels (HR).
Pettigrew (2011)	2	Within subject	HR	Experiencing a Disney theme park did not elicit changes in HR compared to other theme parks.
Price				
Alexander et al. (2015)	90 Age (M = 24.8, SD = 9.6)	Between subjects	HF band	Decrease in HR for consumers who received coupons versus those who didn't receive coupons.

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TABLE 2 (Continued)

Article	Sampling	Design	Measure	Findings
Other				
Cahlíková et al. (2020)	190 (95 females)	Between subject	HR	Stronger physiological stress response leads to lower competition willingness.
Hattke et al. (2020)	136 (83 males) Age (M = 23.37; SD = 3.31)	Between subject	HR	Bureaucratic red tape induces negative emotional reaction.
Falk et al. (2018)	80 (All male)	Between subject	HR	Significant negative relationship between unfair payment on HR variability.
M. Adam et al. (2012)	96 (79 males) Age (M = 22.64)	Between subject	HR	Excitement (HR) is higher in fast versus slow Dutch auctions. High level of excitement leads to lower bids.
Carter (2008)	12	Within subject	HR	Binaural beats did not affect heart rate.

(see Table 2). While heart rate is the most basic and commonly used metric in marketing research, several studies have used alternative and complementary metrics (e.g., RMSSD) derived from the heart rate variability studies. Interestingly, most studies employed time-domain measurements, which does not require understanding of spectral decomposition technique (see Section 2.1). Even so, certain time-domain and frequency-domain indices may share similar physiological correlates (see also Table 1).

4.1.5 | Hardware setup

Traditional devices, that is, nonportable ECG devices used to extract heart rate variability data using specialized software in limited laboratory settings, are being replaced with portable wearable devices that are cheaper and can be used in real-world settings (Dobbs et al., 2019). Although there is debate about the accuracy of traditional versus wearable devices, growing research has found wearable devices to be a good alternative to traditional devices (Nelson et al., 2020). As per our analysis, 11 records did not clearly mention devices in the methodology or procedure sections. Of the remaining records, 59% of studies used non-portable devices and 41% used portable devices. Table 3 lists the studies and associated devices. Records show that the most common non-portable device was the Biopac MP150 system (18%), whereas the most common portable device was from Shimmer systems (14%).

4.1.6 | Complementary tools

In conjunction with heart rate variability devices, our analysis found that studies frequently used electrodermal activity series (48%) and eye tracking (21%) tools. Interestingly, both of these tools are autonomic nervous system based. Electroencephalogram-based studies (18%) capture central nervous system activity (brain signals). Supporting Information: Appendix E highlights complementary tools used across different studies. A detailed review of these tools can be found in Alvino et al. (2020) and Casado-Aranda and Sanchez-Fernandez (2022).

4.2 | Bibliometric analysis

To quantitively analyze our corpus using bibliometric methodology, we followed the guidelines and best practices suggested in Donthu et al. (2021). These can be classified into two broad categories: (a) a performance analysis of publications (i.e., descriptive contribution of articles and journals); and (b) science mapping (i.e., exploring relationships between different research constituents) (Mukherjee et al., 2022).

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TABLE 3 List of devices used to capture the heart rate variability series

Reference (*n* = 22)	Devices	Portability
Luangrath et al. (2022); Ha-Brookshire and Bhaduri (2014)	Biopac MP36	Nonportable
Küster et al. (2021)	PowerLab/16SP	Nonportable
Rodero and Potter (2021); Mas et al. (2020); Alexander et al. (2015); Venkatraman et al. (2015)	Biopac MP150 system	Nonportable
Martinez-Levy et al. (2022); Breuer et al. (2021); Clark et al. (2018)	Shimmer Systems	Portable
So et al. (2021)	Upmood PPG	Portable
Sung et al. (2021)	Empatica E4 wristband	Portable
Simmonds et al. (2020)	PsychLab Peripheral Pulse Amplifier	Nonportable
Falk et al. (2018)	Polar F810i	Portable
Hariharan et al. (2016)	Bioplux sensor system	Portable
Noseworthy et al. (2014)	iWorx PT-104	Nonportable
Maxian et al. (2013); Gangadharbatla et al. (2013)	Coulbourn Instruments bioamplifier	Nonportable
Walla et al. (2011)	Nexus-10-BVP sensor	Nonportable
Pettigrew (2011)	Polar infrared	Portable
Hernandez and Minor (2011)	Burdik EKG10	Nonportable
Carter (2008)	WrisTech HL-168	Portable

4.2.1 | Performance analysis

Using performance analysis, marketing journals were ranked based on their productivity, that is, the total number (Figure 4) and most cited articles using heart rate variability tool (Table 4). Psychology & Marketing with four articles (12%), and PLoS ONE with three articles (9%), were the journals with comparatively more publications out of the 23 journals analyzed. The most cited publications were Venkatraman et al. (2015) with 25.3% of the total citations and Mehta et al. (2012) with 12.9%. Interestingly, while Venkatraman et al. (2015) utilizes other consumer neuroscience tools, Mehta et al. (2012) only used heart rate variability to reflect consumer arousal.

4.2.2 | Science mapping

For science mapping, we conducted an author co-citation analysis (i.e., analyzing relationships among the authors of cited publications) and a co-occurrence analysis (i.e., examining existing interactions between articles based on keywords) (Donthu et al., 2021).

Out of 114 authors involved in 33 articles, only one author was part of three articles—Steven Bellman at the University of South Australia. For the cocitation analysis, we kept the minimum number of citations per author to five. This reduced the number of authors from 3006 to 94. The results are presented in four clusters (red, green, blue, and yellow) in Figure 5. Based on these clusters, Table 5 shows the five most cocited authors in our corpus. Our analysis shows that out of 33 records, 20 documents cited 22 works of Annie Lang 41 times; 15 documents cited 26 works of Peter Lang 38 times; 14 documents cited works of Maragret Bradely 32 times; 13 documents cited 15 works of Robert Potter 26 times; and 8 documents cited 15 works of Michel Wedel 19 times.

For the co-occurrence analysis of keywords, we adapted steps from Veloutsou and Ruiz Mafe (2020). First, keywords were obtained only from 24 records, since the other nine records did not give the authors' or an index of keywords. Second, all keywords with the same meaning were edited or replaced. Specifically, terms such as "brain wave," "galvanic skin response," and "branding" were changed to "electroencephalography," "skin conductance," and "brand." Third, we eliminated keywords that were generic, broad, and unsuitable to the study context. Fourth, in the final set, only 104 out of 117 keywords were found to be interconnected. Figure 6 illustrates the three main clusters derived from the co-occurrence analysis. Cluster 1 represents the consumer neuroscience tools used, along with heart rate variability. Major keywords in this cluster include "electroencephalography," "skin conductance," and "eye tracking." This cluster complements the knowledge presented in Table 5. Cluster 2 indicates the use of heart rate in promotion-related studies. Major keywords here include "heart rate," "advertisement," and "brand." As seen in Table 2, most records fall under the promotion theme of the marketing mix, and cluster 2 verifies this. Cluster 3 highlights emotional appraisal of

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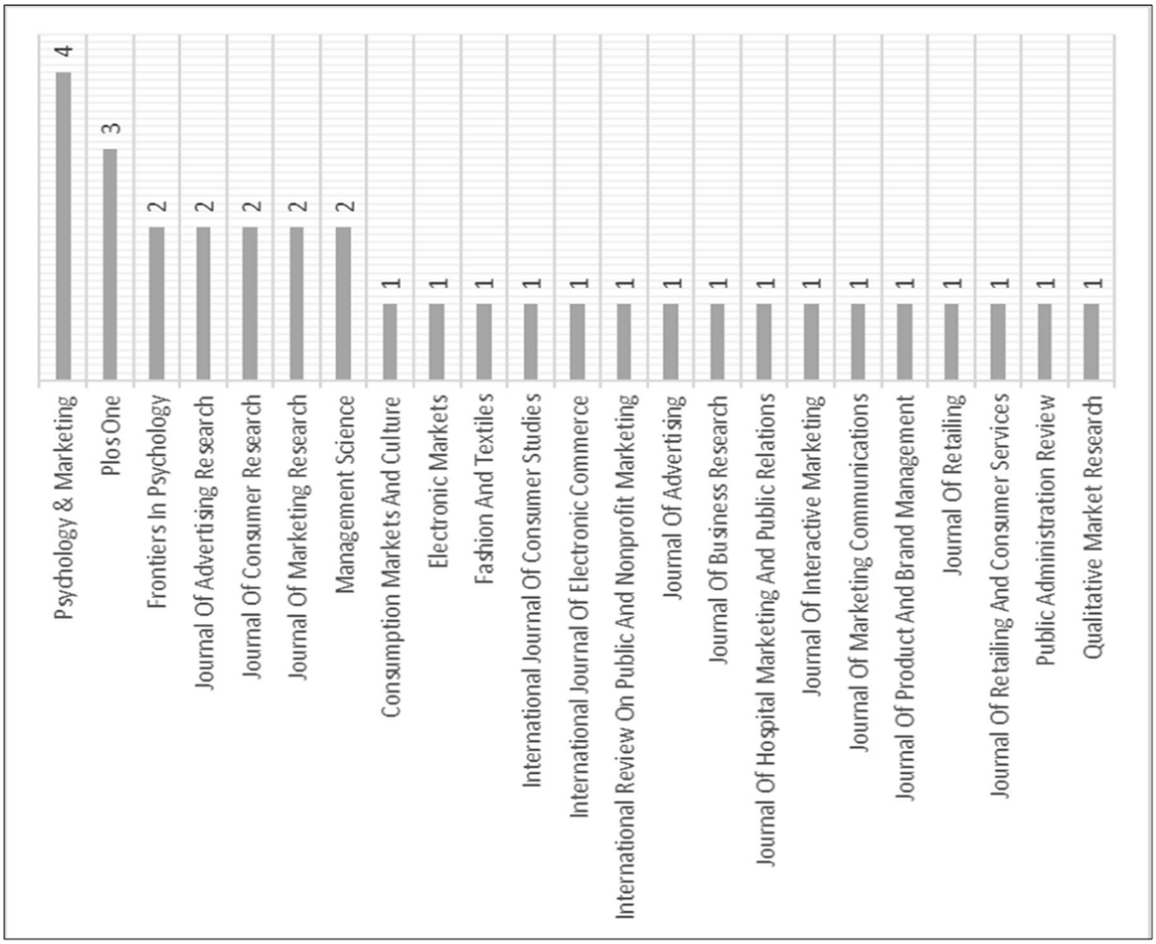

FIGURE 4 Marketing journals with articles that used heart rate variability

TABLE 4 List of top 10 featured articles by citations using heart rate variability

Articles (Year)	Source title (n = 9)	Total citations (n = 960)
Predicting advertising success beyond traditional measures: new insights from neurophysiological methods and market response modeling (2015)	Journal of Marketing Research	243
Is noise always bad? exploring the effects of ambient noise on creative cognition (2012)	Journal of Consumer Research	124
The role of arousal in congruity-based product evaluation (2014)	Journal of Consumer Research	63
Objective measures of emotion related to brand attitude: a new way to quantify emotion-related aspects relevant to marketing (2011)	PLoS ONE	59
Auction fever! how time pressure and social competition affect bidders' arousal and bids in retail auctions (2015)	Journal of Retailing	48
Consumer neuroscience-based metrics predict recall, liking and viewing rates in online advertising (2017)	Frontiers in Psychology	46
Brand love is in the heart: physiological responding to advertised brands (2013)	Psychology and Marketing	44
Excitement up! Price down! Measuring emotions in Dutch auctions (2012)	International Journal of Electronic Commerce	44
Psychophysiological response patterns to affective film stimuli (2013)	PLoS ONE	36
Emotional responses to bureaucratic red tape (2020)	Public Administration Review	35

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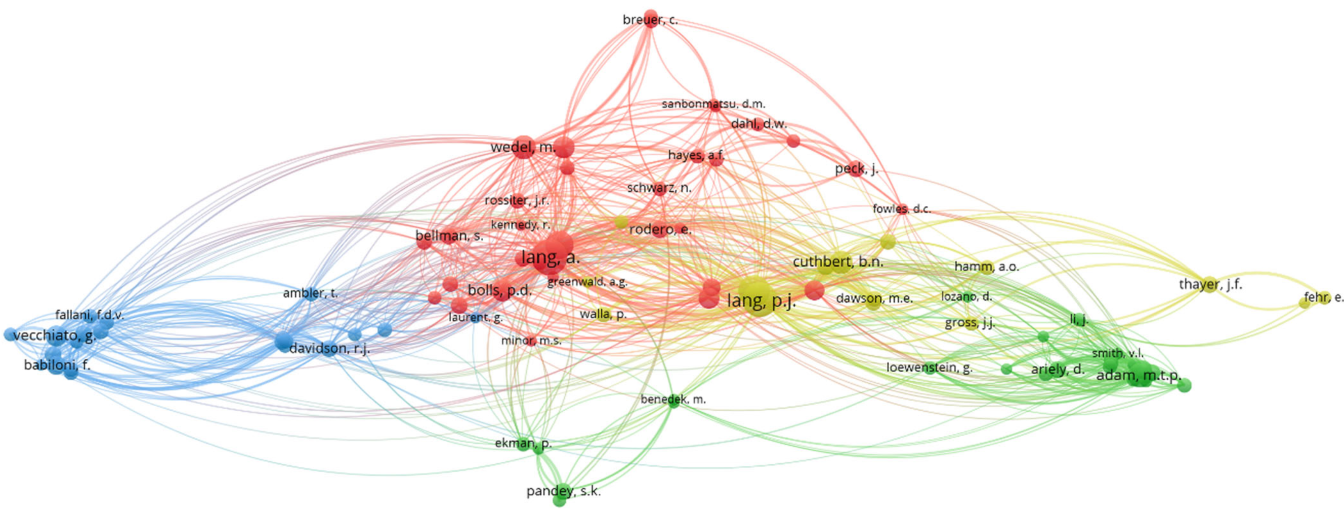

FIGURE 5 Cocitation analysis of most cited authors using VOSviewer (Van Eck & Waltman, 2010)

TABLE 5 List of cocited authors with the most citations and their most influential work

Citations	Author	University	Most referred work	Cluster
41	Annie Lang	Indiana University Bloomington	The limited capacity model of mediated message processing (2000)	Red
38	Peter Lang	University of Florida	Emotion and motivation i: defensive and appetitive reactions in picture processing (2001)	Yellow
32	Margaret Bradley	University of Florida	Emotion and motivation i: defensive and appetitive reactions in picture processing (2001)	Yellow
26	Robert Potter	University of Alabama	Psychophysiological measurement and meaning (2012)	Red
19	Michel Wedel	University of Maryland	A review of eye-tracking research in marketing (2008)	Red

the organism that forms the experience. Major keywords here are "emotion," "arousal," and "facial expression."

4.3 | Research avenues

Based on our analysis and expertise in marketing and psychophysiological signal processing, we propose six research avenues blending consumer centric SOR theory and traditional 4P marketing mix for potential marketing research. Following Loureiro et al. (2020) for future research directions, we divided our proposals in three distinct, but related, aspects of theory, characteristics, and methodology. Subsequently, Table 6 provides research questions for future studies.

4.3.1 | Theory: New research directions

Most of the papers addressed isolated topics without any theoretical integration with marketing or consumer decision-making. The first avenue embraces consumer decision-making elicited by any 4P marketing mix through affective, cognitive, and sensorial constructs. Marketing researchers and practitioners stand to gain from understanding the physiological effects of emotions, as they play a vital role in consumer decision-making (Gaur et al., 2014). Emotional influence on consumer decision-making is categorized as integral (induced by advertisements, events, etc.) and incidental (brand choice, risk taking, etc.) (Achar et al., 2016). Valenza et al. (2014) used a probabilistic approach to analyze heartbeat dynamics, categorizing four emotional states based on the circumplex model of affect and using heart rate variability-derived features. The basic emotion approach classifies emotions into discrete categories (surprise, anger, joy, fear, etc.) evoked by marketing mix stimuli (Laros & Steenkamp, 2005). Additionally, the research has shown heart rate variability to be a physiological correlate of different cognitive domains, such as memory, attention, executive functions, and visuospatial skills (Forte et al., 2019), as well as cognitive load (Solhjoo et al., 2019). Research has also demonstrated the relationship between flow state and heart rate variability (Tozman et al., 2015).

4.3.2 | Characteristics: New research directions

The second avenue considers personality, thinking style, and demographics. This set of variables can be considered as consumer profiles for decision-making. Zohar et al. (2013) highlighted

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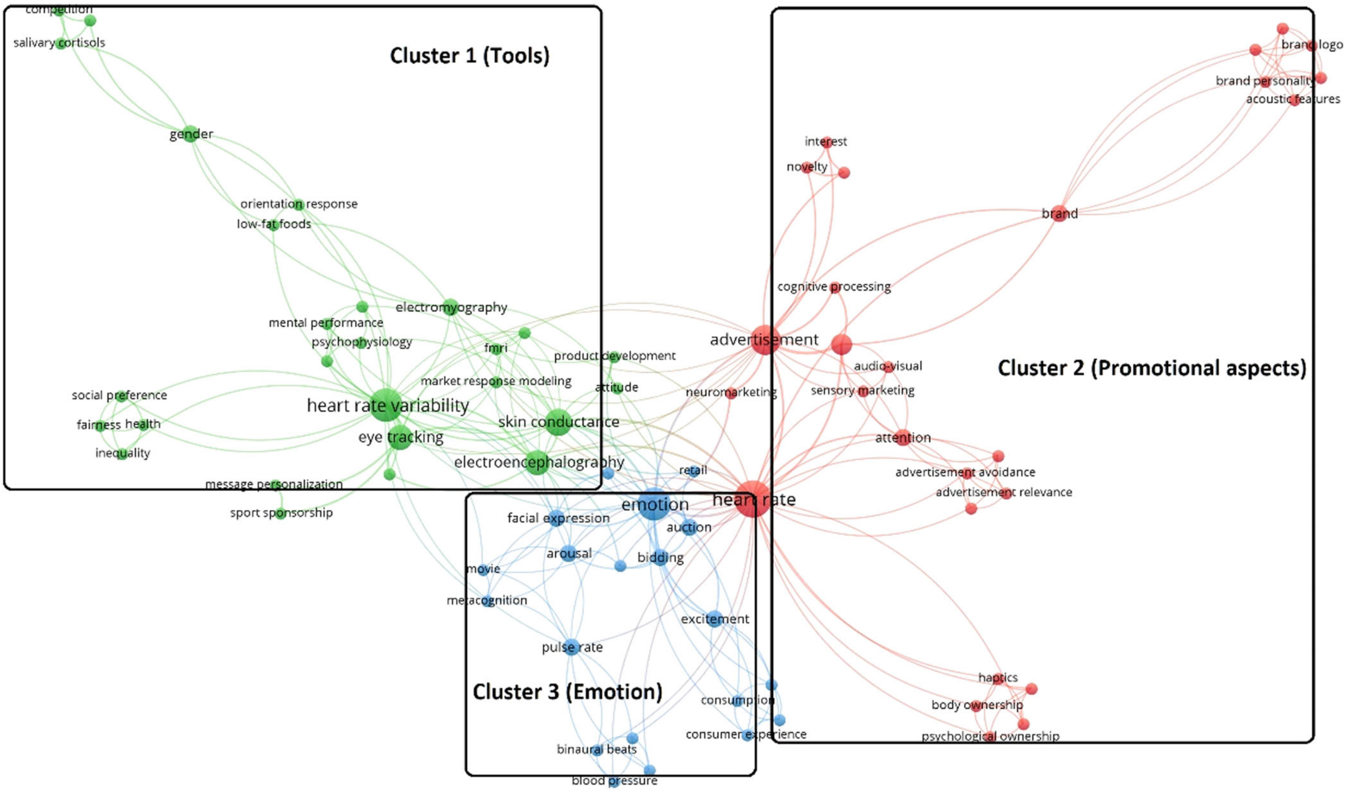

FIGURE 6 Keyword co-occurrence analysis using VOSviewer (Van Eck & Waltman, 2010)

TABLE 6 Overview of research questions involving the use of heart rate variability

Research directions	Research avenues	Research questions
Theory	Consumer decision-making involving affective, cognitive, and sensorial constructs	Can heart rate variability dissociate rational and impulse buying of different product types such as hedonic and functional? Can heart rate variability series be used to predict the influence of product attributes or retail features on purchase behavior? How do various sensory touch points (e.g., scent, music, light, touch, and taste) influence heart rate variability and lead to purchase decisions? As consumers' emotional and cognitive factors are associated with brand experience (Plassmann et al., 2012), what insights into their underlying physiology can be inferred from the use of heart rate variability?
Characteristics	Personality, thinking style, and demographics Product experience Promotional aspects (advertising and branding)	How do heart rate variability metrics differ based on personality traits, thinking styles, and demographics (e.g., gender and age)? How do these consumer responses evolve over time, framed by social interactions and environmental conditions (e.g., time and multitasking)? How can continuous recording of heart rate variability detect consumers' experience and engagement with the products or services? How can heart rate variability infer a dissociative effect of space and time dimensions of the physical and virtual retail store on consumers' purchase behavior? How can portable heart rate variability devices be used to pretest or profile consumers for personalized and effective advertisements? Can heart rate variability assist in improving behavioral targeting of advertisements? How can heart rate variability analysis complement other biometric tools to improve detection of discrete consumer emotional responses (e.g., joy, fear, and sadness) to advertising content?

(Continues)

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TABLE 6 (Continued)

Research directions	Research avenues	Research questions
		How can heart rate variability captured through portable devices be improved to track consumers' affective states throughout the day? What insights can be derived from heart rate variability into consumers' attention and arousal toward advertising content?
Methodology	Correlation with immersive technologies Triangulation with neurophysiological tools	How can heart rate variability devices integrate with augmented and virtual technologies for capturing consumers' experiences in the metaverse environment? How can heart rate variability series data be corroborated with other consumer neuroscience tools to accurately forecast behavior? Can the use of machine-learning algorithms and artificial intelligence improve heart rate variability analysis to detect consumer emotions better?

significant associations between distinctive participant personality traits and heart rate variability metrics. Novel constructs, such as aggression (Kristofferson et al., 2017), can be correlated with heart rate variability indices (Zohar et al., 2013), thereby providing a refined understanding of consumer behavior

The third avenue addresses product experience at the point of sale and during consumption and usage. Alvino et al. (2020) highlighted the use of consumer neuroscience tools to study product experiences in retail stores. The LF/HF ratio as an heart rate variability metric may be useful for identifying the stress levels of individuals in controlled environments (Dulleck et al., 2011). The relationship between heart rate variability metrics and positive experiences should be further explored, as they may impact behavioral intentions, such as willingness to pay, patronage, and real purchase behavior. Customer experience involving the space–time dimensions of physical retail stores, including digital settings and virtual reality, can be informed via heart rate variability metrics. The space dimension of retail store can influence product allocations, store ambience (color, lights, or music), store crowdedness, and stimuli information (size, price tags, displays, packaging, or branding). The crowd level in retail stores may influence the psychological stress state due to limited space (Stokols, 1972). The time dimension refers to the saliency of stimuli over time, and heart rate variability could contribute to the measurement of arousal and excitement during a shopping trip to a retail store.

The fourth avenue focuses on advertising and branding. Almost 25% of heart rate variability studies examined the impact of several types of advertisement (e.g., television, trailers, YouTube videos, video games) on emotions (valence and arousal), cognitive processes (attention, engagement, memory, etc.), and consumer behavior (preferences, satisfaction). Continuous response remains a challenge when delivering message content (e.g., subsequent exposure to an ad, affect to arousal). In advertising research, it is useful to delineate the influence of frames, objects and subjects, and layout. A/B testing, or more sophisticated testing, represents an excellent opportunity to measure continuous emotional reaction to advertising content or formats and variations. Additionally, continuous measurements of time stimuli, such as video ads or online search, might provide variations over time indicating consumer responses to specific elements of each stimulus, such as size, colors, logos, and claims.

4.3.3 | Methodology: New research directions

The fifth and sixth avenues address the correlation between heart rate variability and immersive and neurophysiological tools. In recent years, heart rate variability has been increasingly used in many fields to complement mixed reality systems (Halbig & Latoschik, 2021). Virtual reality enables consumer researchers to depict a variety of real-world situations with a suitable level of details, contextual elements, and sensory information, which allows for high ecological validity during experimentation. Carefully chosen stimuli relevant to marketing applications can evoke a range of experiences, such as stress, presence, enjoyment, or anxiety, which can be precisely correlated with physiological data. Studies published in the last decade in consumer research journals show that heart rate variability measurements are often used in conjunction with other neuroscientific tools, such as eye tracking and electroencephalography (see Supporting Information: Appendix E). Furthermore, machine-learning algorithms may be applied to identify consumers' emotional experiences by utilizing features extracted from heart rate variability series. Random forest, k-nearest neighbor, and support vector machine are classifiers commonly used by researchers (see Bulagang et al. (2020) for a review).

5 | GUIDELINES AND IMPLICATIONS FOR PLANNING HEART RATE VARIABILITY STUDIES IN MARKETING

In this section, we outline general instructions for the new researchers or nonexpert readers.

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(i) *Designing an empirical study with heart rate variability*: (a) At the initial stage, the researcher should choose the stimulus type (interactive, multisensorial, or static) as categorized by the themes in Table 2; (b) the study context (natural vs. artificial environment) should be selected; (c) the type of device used to capture heart rate variability should be chosen (see Table 3); and (d) the sample size of the study should be based on research design and sample criteria (see Section 4.1.3). It is recommended that sample size is estimated using power analysis (e.g., GPower 3.1) based on the study design, as sample size can significantly influence the outcomes of statistical tests; and (e) the choice of analysis and suitable measurement are dependent upon the study's objectives and the researcher's expertise.

(ii) *Recommendation for choosing measurements*: From a methodological viewpoint, it is quite difficult to perform a comparison analysis between heart rate variability measurements defined in time, frequency, and nonlinear domains. These measurements, in fact, maybe redundant with respect to their physiological correlates (e.g., cardiac parasympathetic activity may be linked to RMSSD in the time domain and HF power in the frequency domain), while they may show different statistical power in a given task discerning marketing behaviors. We recommend the use of time domain measurements especially in case of short-term recordings (i.e., less than 1 min), and the use of frequency domain measurements in recordings of length between 2 and 5 min. Beyond the spectral paradigm, effective measurements with specific physiological correlate should be used, maybe in a time-resolved fashion (Valenza et al., 2018). In case of longer recordings, analysis in the frequency domain should be performed through time-resolved methods (e.g, time-varying spectral analysis). Nonlinear analysis may be performed in series longer than 5 min. Of note, nonlinear analysis is more sensitive to fast changes and spikes in the series than time and frequency analyses.

(iii) *Participants' characteristics*: Various combinations of exogenous and endogenous factors can contribute to confounding in heart rate variability analysis. It is important that researchers pay detailed attention to participants' age, lifestyle (smoking, alcohol consumption, drug use, coffee intake, etc.), pathological conditions, and fitness levels for accurate measurement comparisons (Acharya et al., 2006).

(iv) *Data triangulation***:** This process involves data correlation attained via multiple methods (quantitative or qualitative) or techniques (behavioral, physiological, or neurophysiological) to make behavioral predictions. Researchers should acknowledge that heart rate variability can be correlated with consumer arousal levels and their emotional valence (positive or negative). This provides an incentive to validate heart rate variability measures with other consumer neuroscience tools (see Supporting Information: Appendix E) and rigorously validated selfreports, to provide a robust picture of consumer emotions (Mcaleer et al., 2022). In their recent work, Baldo et al. (2022) concurrently used heart rate variability, electrodermal activity, electroencephalography, and selfreport responses to examine the effect of stimulus type (images, videos, and TV advertisements) on consumer decision-making. The results revealed that heart rate variability correlates with selfreport valence and predicts advertisement and brand recognition. Across the stimulus type, heart rate variability reliably recognized differences between positive and negative valence, whereas electrodermal activity consistently correlated with selfreport arousal. While heart rate variability was not a significant predictor of the purchase intention, frontal alpha asymmetry obtained from electroencephalograms significantly predicted purchase intent. Taken together, the complementary nature of the techniques provides various sources of data to help forecast attitude and subsequent behavior.

(v) *Statistical factors*: Checking the normality of physiological data is essential. The heart rate variability series may not be normally distributed, requiring nonparametric approaches or bootstrapping methods for inferential analysis (Massaro & Pecchia, 2019). Nonparametric approaches, such as fast Fourier transform, are simpler to employ with high processing speed compared to parametric approaches (Malik et al., 1996).

6 | CONCLUSION

Heart rate variability is emerging as a reliable, accurate, and valuable noninvasive tool for capturing consumer physiological and emotional responses. Despite gaining prominence in varied research domains, heart rate variability methodology is a daunting task for marketing researchers. The present study is the first to conduct a comprehensive literature review on the use of heart rate variability in marketing research. Previous research has scarcely utilized its full potential and has often been used as a complementary tool. To overcome this limitation, this literature review provides twofold contributions: (1) develops a conceptual framework that provides a structured overview of the evolution of heart rate variability tools over the past two decades and prominent topics covered in marketing research; and (2) provides research avenues and guidelines for theoretical and practical exploration in the marketing domain. Our review offers perspectives to both practitioners and researchers alike, making it a worthwhile contribution.

Our literature review attempts to assist future marketing researchers with the use of heart rate variability. To achieve this aim, we interspersed the production-oriented marketing mix (Constantinides, 2010) with the consumer-centric SOR framework. Regarding the most frequent topics investigated through heart rate variability, promotional aspects dominate previous marketing research, followed by product aspects of the marketing mix. Regarding measurements, heart rate is used most frequently. Further, the time-domain measurements are the most common. Regarding data collection, ECG devices are being replaced by portable or wearable devices placed on fingers or wrists.

A deeper analysis of the topics addressed in previous papers was performed through a co-occurrence analysis of keywords, showing

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three cluster topics: (1) consumer neuroscience tools used, along with heart rate variability; (2) heart rate in promotional issues; (3) highlighting emotional appraisal of the organism that forms the experience. These results indicate the complementary nature of heart rate variability with other neurophysiological tools, its focus on promotional issues, and its suitability for measuring emotions.

Based on our analysis, we suggest six main research avenues. First, the consumer decision-making elicited by any of the 4Ps with a special focus on emotional effects. Second, as heart rate variability relates to the subject's nervous system, we advocate for new research that goes deeper regarding personality, thinking style, and demographics and their relationship with heart rate variability. Third, consumer experience at the point of sale and during consumption or usage might be a fruitful research area for heart rate variability. Fourth, as advertising stimuli trigger emotional effects, continuous heart responses to such stimuli become a useful research area. Fifth, integrating heart rate variability with immersive technologies can provide an opportunity for capturing novel affective and cognitive constructs with high ecological validity. Sixth, using heart rate variability with other neurophysiological tools provides immense potential for predicting consumer behavior.

Additionally, we emphasize that future research should consider the two key ethical dimensions with respect to its use for marketing research. First, the protection of participant confidentiality, privacy, and informed consent should be an unwavering commitment of the researcher. Second, the reporting of the analysis and subsequent findings should be rigorously valid, interpretable, and transparent.

6.1 | Limitations and directions for future research

This study comes with two drawbacks that may provide opportunities for future researchers. From the methodological perspective, our database held only journal articles and no conference papers. The latter may point to emerging research relevant for understanding heart rate variability in the marketing context. The exclusion of marketing-allied subject areas (e.g., tourism and hospitality) limits deeper contributions of the heart rate variability tool.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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