Sketching the first 45 years of the journal Psychophysiology (1964–2008): A co-word- based analysis

MARIA ISABEL VIEDMA-DEL-JESUS,[a,b] PANDELIS PERAKAKIS,[c] MIGUEL ANGEL MUNOZ,[a,d] ANTONIO GABRIEL LOPEZ-HERRERA,[e] and JAIME VILA[a]

[a]Department of Personality, University of Granada, Granada, Spain

[b]Department of Marketing and Market Research, University of Granada, Granada, Spain

[c]Laboratory of Experimental Economics, University Jaume I, Castellon, Spain

[d]Department of Psychology, University of Balearic Islands, Palma, Spain

[e]Department of Computer Science and Artificial Intelligence, CITIC-UGR (Research Center on Information and Communications Technology), University of Granada, Granada, Spain

Abstract

This article presents a keyword-based bibliometric study of the thematic evolution of the journal Psychophysiology since its first publication in 1964 until 2008. Bibliometric maps showing the most relevant associations among the main topics treated by the journal are provided separately for the periods 1964–1978, 1979–1988, 1989–1998, and 1999–2008. These maps offer insight into the conceptual structure of psychophysiology as a research discipline and help to visualize the division of the field into several interconnected subfields. Bibliometric maps created by co-word analysis can be used by both experts and novices to understand the current state of the art of a scientific field and to predict where future research could lead.

Descriptors: Psychophysiology, Bibliometric studies, Co-word analysis, Scientific structure, Conceptual development

Introduction

Psychophysiology is a scientific discipline that has experienced a high rate of growth compared to other disciplines within psychology. A bibliometric study published in 1996 showed a mean half-life of 6.5 years for articles published in the journal Psychophysiology since its first issue in 1964 until 1993 (Sanchez- Hernandez, Pedraja,

Quinones-Vidal, & Martınez-Sanchez, 1996). This short half-life index implies a constant evolution of the discipline similar to that observed in the experimental and natural sciences and probably reflects the dependence of psychophysiological research on rapidly evolving scientific fields such as physics, mathematics, and engineering. Innovations in these fields are bound to lead, sooner or later, to significant breakthroughs in psychophysiological research.

In spite of the corroborating evidence demonstrating that psychophysiology is a lively and rapidly evolving scientific discipline, to our knowledge, no other study has provided concrete bibliometric information, based on the journal Psychophysiology, after 1993. The aim of the present study is twofold: first, to extend the analysis period to 2008 and, second, to complement the previous bibliometric data with new thematic analyses based on the associations between key concepts (co-word analysis). Bibliometric maps based on co-word analysis help to visualize the division of one field into several subfields and their relationships, providing interesting insight into the evolution of the main topics being discussed in the field through- out the years (Cho & Khang, 2006; Echchakoui & Mathieu, 2008).

The journal Psychophysiology was chosen as our target be- cause of its acceptance among psychophysiologists as one of the most valuable and influential sources of information in the field. The choice of this journal also facilitates the discussion of our results in relation to those provided by Sanchez-Hernandez et al. (1996) and by another bibliometric study published in Psycho- physiology focused on the early years of the field, from 1930 to 1964 (Holguın & Cadaveira, 2003).

Co-word analysis is a content analysis technique that is effective in mapping the strength of association between information items in textual data (Callon, Courtial, Turner, & Bauin, 1983; Callon, Courtial, & Laville, 1991; Coulter, Monarch, & Konda, 1998; Whittaker, 1989). It is a powerful technique for discovering and describing the interactions between different fields in scientific research (Callon et al., 1991; Cobo, Lopez-Herrera, Herrera-Vied- ma, & Herrera, 2011; Bailon-Moreno, Jurado-Alameda, & Ruız- Banos, 2006; Leydesdorff & Zhou, 2008; Lopez-Herrera et al.,

2009; Lopez-Herrera, Cobo, Herrera-Viedma, & Herrera, 2010; Zhang, Wolfram, Wang, Hong, & Gillis, 2008). Co-word analysis reduces the distance between descriptors (or keywords) to a set of network graphs that effectively illustrate the strongest associations between the descriptors (Coulter et al., 1998).

The basic assumption in bibliometric mapping (Borner, Chen, & Boyack, 2003) is that each research field can be characterized by a list of important keywords. Each publication in the field can, in turn, be characterized by a sublist of these global keywords that can be used as a similarity measure: The more keywords two documents have in common, the more similar the two publications are and the more likely they come from the same research area or research specialty at a higher level.

According to Borner et al. (2003), the process of constructing a bibliometric map can be divided into the following six steps: (1) collection of raw data, (2) selection of the type

of item to be analyzed, (3) extraction of relevant information from the raw data, (4) calculation of the similarities between items based on the extracted information, (5) positioning of items in a low-dimensional space based on their similarities, and (6) visualization of the low-dimensional space. In the following section, the way in which each of these steps was implemented is described.

Method

Collection of Raw Data. This article presents a corpus of raw data containing 3,517 articles published in the journal Psychophysiology that was extracted on January 8, 2009, from the ISI Web of Science using the following query:

SO=Psychophysiology; where SO field is a search based on the JournalTitle:

Four sets of data were collected, one for each period studied: 1964–1978, 1979–1988, 1989–1998, and 1999–2008. In this way, separate bibliometric maps could be constructed for each of the four periods.

Selection of the Type of Item for the Analysis. According to Borner et al. (2003), journals, articles, authors, and descriptive terms or words are the most commonly analyzed items. Each type of item provides a different visualization of the field of science being studied and results in a different analysis. In this article, descriptive words and, more concretely, keywords were chosen. For the purposes of our study, a bibliometric map showing the associations between keywords in a scientific field is referred to as a keyword-based map.

Extraction of Relevant Information from the Collected Raw Data. In this article, the relevant information consisted of the co- occurrence frequencies of the keywords. The co-occurrence frequency of two keywords is extracted from the corpus of articles by counting the number of articles in which the two keywords occur in the keywords section. Prior to counting, a process of keyword filtration was implemented to avoid the duplication of keywords with identical meanings or to join with hyphens words describing a single keyword. In our study, the list of equivalences was limited to synonymous or almost synonymous keywords, for example, skin-potential and palmar- skin-potential, orienting-response and orienting-reflex, stress and stress-reactions. Keywords very closely related but different in meaning were kept separate; for example, skin-resistance and skin-conductance, physiological-stress and psychological-stress, evoked-potential and auditory-evoked-potential, or startle-reflex and eyeblink-reflex.

Calculation of Similarities between Items. The fourth step in the process of bibliometric mapping is the calculation of similarities between items based on the information extracted in the third step. In this article, similarities between items were calculated based on the co-occurrence frequencies of the keywords. The minimum number of co-occurrences for each period was 4. When two keywords frequently occur together,

they are considered linked, and the intensity of the link is indicated by the equivalency index e_{ij} (Michelet, 1988), defined as

$$e_{ij} = \frac{c_{ij}^2}{ci^* cj},$$

where c_{ij} is the number of documents in which two keywords, i and j, co-occur, and c_i and c_j represent the number of documents in which each one appears. When the keywords always appear together, the equivalency index equals unity; when they are never associated, it equals zero. Once the links are quantified, an algorithm called simple centers (Coulter et al., 1998) produces groupings of themes. The simple centers algorithm makes two passes through the data to produce the desired networks. The first pass constructs networks depicting the strongest associations; links added in this pass are called internal links. The second pass adds links of lesser strengths that form associations between networks. The links added during the second pass are called external links.

The density of a network (the internal cohesion index) measures the internal strength of the network and is defined as

$$d = 100 \cdot \frac{\sum e_{ij}}{w},$$

where i and j are keywords belonging to the theme and w is the number of keywords in the theme. The centrality of a network (the external cohesion index) measures the degree of interaction with other networks and is defined as

$$c = 10 \cdot \sum e_{kh},$$

where k is a keyword belonging to the theme and h a keyword belonging to other themes. Isolated networks are those that have low centrality values. Principal networks (also called motor-themes) are those that have high centrality and high density values.

Positioning of Items in a Low-Dimensional Space. The fifth step is the positioning of the items in a low-dimensional space based on the similarities calculated in the fourth step. In this article, the low-dimensional space is referred to as a keyword-based map, and only two-dimensional keyword-based maps are considered. The two dimensions are centrality rank (c_r) and density rank (d_r), calculated as

$$c_r = \frac{rank_i^c}{N}; d_r = \frac{rank_i^d}{N},$$

where $rank^c$ is the position of the theme i in the theme list in ascending order of centrality, and $rank^d$ is the position of the theme i in the theme list in ascending order of density. N is the number of themes in the whole network. N is introduced to standardize the c_r and d_r values between 0 (lowest rank) and 1 (highest rank).

Visualization of Results in the Low-Dimensional Space. The CoPal Red (EC^3, 2006) computer program was used to visualize the networks in a two-dimensional space called a strategic diagram. A strategic diagram is a two-dimensional space built by plotting themes according to their centrality and density rank-values along two axes:

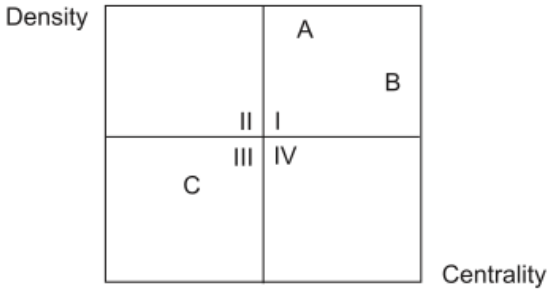

Figure 1. An example of strategic diagram.

x-axis centrality and y-axis density. An example of a strategic diagram is presented in Figure 1. The abscissa axis is centrality, or the external cohesion index. It represents the more or less central position of the theme within the overall network. The ordinate axis is density, or the internal cohesion index. It represents the more or less conceptual development of the theme. The themes in quadrant I (upper-right) are considered the motor- themes of the specialty because they present strong centrality and high density. Themes in quadrant II (upper-left) are considered very specialized themes, with high density but weak external interconnections, whereas those in quadrant III (lower-left), with low density and little centrality, represent either emerging or disappearing themes. Themes in quadrant IV (lower-right) are considered the general basic themes, with strong centrality but low internal development.

In strategic diagrams, themes are represented by spheres of different volumes, which are organized in the quadrants according to their internal and external cohesion (density and centrality, respectively). The volume of the spheres is proportional to the number of documents (indicated below the theme label) corresponding to each theme. In our study, the label of the themes in the strategic diagrams was dictated

by the keyword with the highest volume in the network[1]. The thematic networks complement the strategic diagrams. In thematic networks, connecting lines represent the internal and external relations among the themes (links). Here, the thickness of the link between two nodes (keywords), i and j, is proportional to the equivalence index e_{ij}, which ranges from 0 to 1.

Results

Figures 2 to 6 show the strategic diagrams and the thematic networks corresponding to the four periods under examination (1964–1978, 1979–1988, 1989–1998, and 1999–2008). These graphs are used in the following sections to describe the internal and external cohesion of the themes within each period and their associated thematic networks. Uppercase letters are used to indicate the themes in the strategic diagrams and lowercase letters to indicate the keywords in the thematic networks.

Period 1: 1964–1978.

Strategic diagram. In the first period (1,256 published articles), eight major themes were identified by keywords representing five physiological measures (HEART-RATE, ELECTRODERMAL-ACTIVITY, ELECTROENCEPHALOGRAPHY, EVOKED- POTENTIAL, and ELECTRICAL-ACTIVITY) and three psychological research areas (SLEEP, CLASSICAL-CONDITION- ING, and BIOFEEDBACK). Because of their strategic position (upper-right quadrant), three themes were identified as the motor-themes of the period: SLEEP, HEART-RATE, and ELECTRO- DERMAL-ACTIVITY (see Figure 2). Because of its high/medium density and low centrality (upper-left quadrant), CLASSICAL-CONDITIONING was regarded as a specialized theme with high conceptual development but weak external interconnection. Sim- ilarly, because of its high/medium centrality and low density (lower-right quadrant) ELECTROENCEPHALOGRAPHY was regarded as a general basic theme with strong external interconnection but low conceptual development. However, the strategic position of ELECTRICAL-ACTIVITY, BIOFEEDBACK, and EVOKED-POTENTIAL (lower-left quadrant), which had low density and low centrality, indicated that they were either emerging or disappearing themes.

Thematic network. The thematic network of this period helps to characterize each of the themes in relation to their internal and external cohesion. As can be seen in Figure 3, the three motor- themes, SLEEP, HEART-RATE, and ELECTRODERMAL- ACTIVITY, had numerous internal and external connections forming thematic subclusters. HEART-RATE showed a complex network of internal connections with cardiovascular-system, blood-pressure, respiration, skin-conductance, skin-resistance, and operant-conditioning and external connections with

---

[1] There were two exceptions: (a) in Period 4, two keywords having similar volumes were both included in the theme label (CARDIOVASCULAR-REACTIVITY/HEART-RATE) and (b) themes related to electrodermal activity but with different labels (GALVANIC SKIN-RESPONSE in Periods 1 and 4 and SKIN-RESISTANCE in Periods 2 and 3) were both labeled ELECTRODERMAL-ACTIVITY.

ELECTRODERMAL-ACTIVITY and ELECTRICAL-ACTIVITY. Similarly, the SLEEP network had internal connections with eye-movement, electromyography, REM-sleep, dream, and drugs and external connections with ELECTROENCEPHALOGRAPHY and BIOFEEDBACK. However, themes with few internal or external interconnections tended to appear isolated, such as EVOKED-POTENTIAL, which had little density (radial disposition of the network around the central keyword), and CLASSICAL-CONDITIONING, which had little centrality (few and weak connections with other themes).

Period 2: 1979–1988.

Strategic diagram. In this period (737 published articles), eight major themes were identified, six representing physiological mea- sures (HEART-RATE, ELECTRODERMAL-ACTIVITY, ELECTROENCEPHALOGRAPHY, EVOKED-POTENTIAL, AUDITORY-EVOKED-POTENTIAL, and PHYSIOLOGI- CAL-CORRELATES), one representing a psychological research area (SLEEP), and one representing a methodological procedure (AUDITORY-STIMULATION). The number of motor-themes increased from three to five. HEART-RATE and SLEEP were again motor-themes. The new motor-themes were EVOKED- POTENTIAL, PHYSIOLOGICAL-CORRELATES, and AU- DITORY-STIMULATION. Three themes, present in the previ- ous period, disappeared: CLASSICAL-CONDITIONING, BIOFEEDBACK, and ELECTRICAL-ACTIVITY. Two addi- tional themes that were also present in the previous period, ELECTROENCEPHA-LOGRAPHY and ELECTRODERMAL-ACTIVITY, decreased in density and centrality and had relocated to the lower-left quadrant, suggesting that they might be disap- pearing themes. Finally, a new theme, AUDITORY-EVOKED- POTENTIAL, which is different from EVOKED-POTENTIAL, appeared in the lower-left quadrant, suggesting that it might be an emerging theme.

Thematic network. The thematic network of this period (see Figure 4) clearly shows the high centrality and density of HEART-RATE. It is characterized by keywords related to other cardiovascular variables and various stress-related concepts. The HEART-RATE network also showed strong external interconnections with PHYSIOLOGICAL-CORRELATES, other motor-theme in this period with internal networks formed by cardio-respiratory variables, and research topics related to motivational and emotional processes. EVOKED-POTENTIAL became a motor-theme in this period because it had higher density and centrality than in the previous period. It showed internal connections with reaction-time, motor-processes, and performance, and external interconnections with SLEEP, AUDITORY-EVOKED- POTENTIAL, and ELECTROENCEPHALOGRAPHY. AU- DITORY-STIMULATION appeared for the first time as a motor-theme, with high density and moderate centrality. It included keywords that describe stimulus parameters, like intensity and duration, and specific research areas, like habituation, orienting- response, and startle-reflex; it also had various external connections with ELECTRODERMAL-ACTIVITY, the theme with the lowest density and centrality in this period.

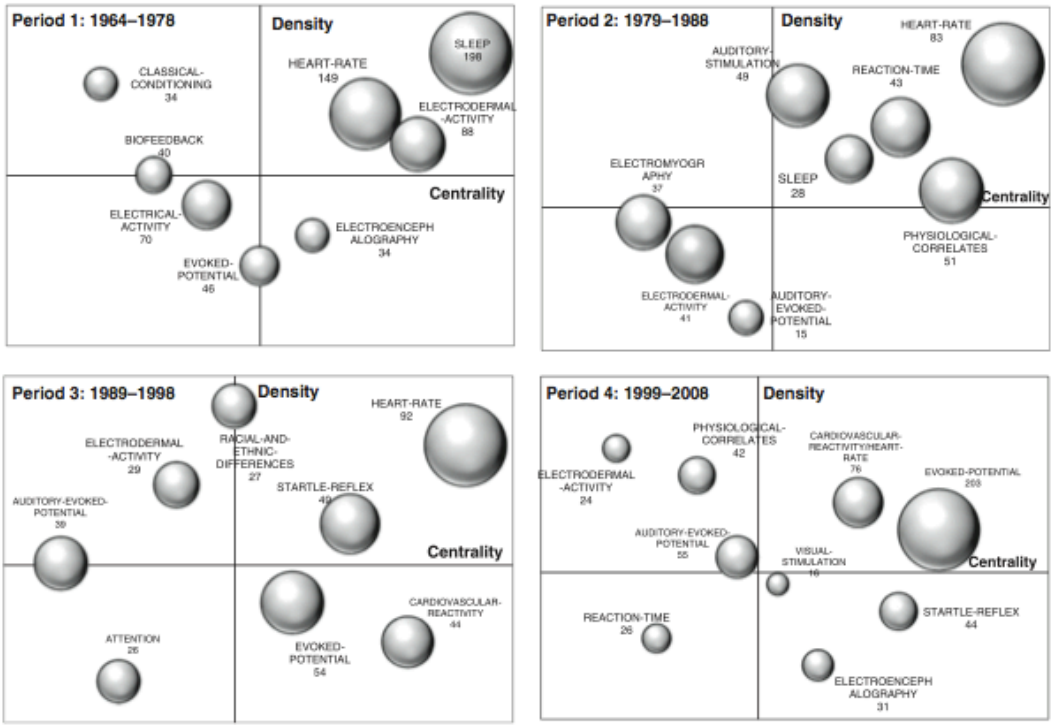

Figure 2. Strategic diagrams for the four periods.

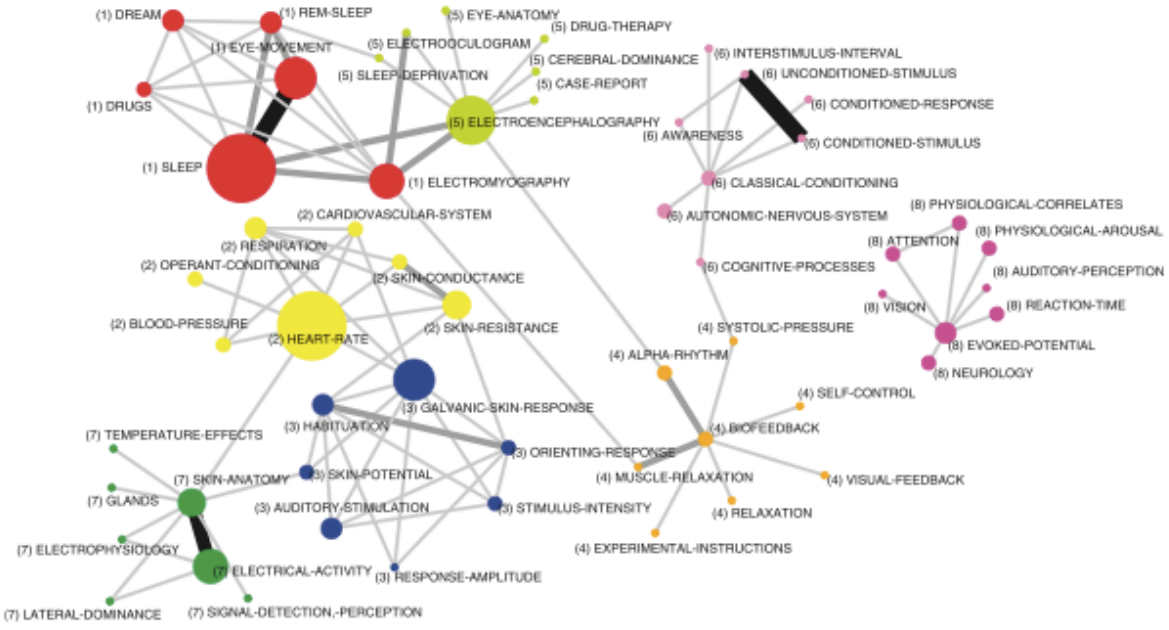

Figure 3. Thematic network of Period 1: 1964–1978.

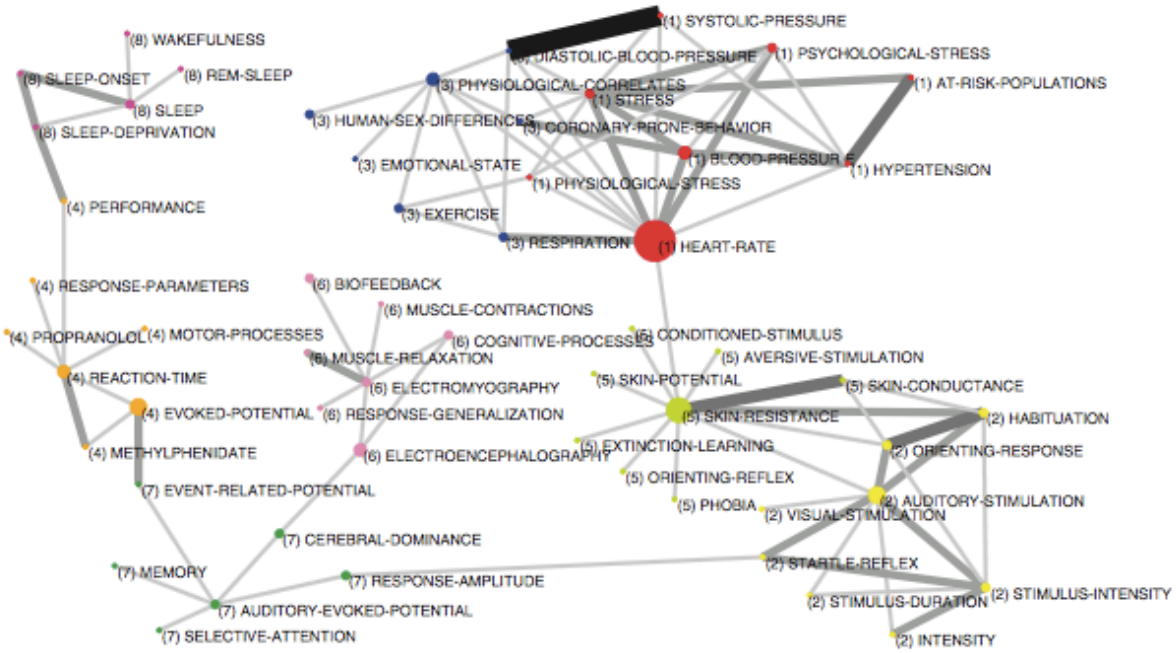

Figure 4. Thematic network of Period 2: 1979–1988.

Period 3: 1989–1998.

Strategic diagram. In the third period (645 published articles), eight major themes were also identified, six representing physiological measures (HEART-RATE, ELEC- TRODE- RMAL-ACTIVITY, EVOKED-POTENTIAL, AUDITORY- EVOKED-POTENTIAL, STARTLE-REFLEX, and CARDIO- VASCULAR-REACTIVITY) and two representing psycholog- ical research areas (ATTENTION and RACIAL-AND- ETHNIC-DIFFERENCES). In this period, only two motor- themes were found: HEART-RATE and STARTLE-REFLEX. STARTLE-REFLEX appeared for the first time as an independent theme. EVOKED-POTENTIAL showed some decrease in density compared to the previous period and had relocated to the lower-right quadrant. AUDITORY-EVOKED-POTENTIAL continued as an independent theme; but it was still located in the lower-left quadrant as a disappearing or emerging theme. ELECTRODERMAL-ACTIVITY, on the contrary, left this quadrant, having increased in both density and centrality, and was relocated in the upper-left quadrant but with a signifi- cant reduction in number of articles. Three themes, present in the previous period, disappeared: ELECTROENCEPHALO-GRAPHY, PHYSIOLOGICAL-CORRELATES, and AUDI- TORY-STIMULATION. Three new themes, in addition to STARTLE-REFLEX, appeared: CARDIOVASCULAR- REACTIVITY, RACIAL-AND-ETHNIC-DIFFERENCES, and ATTENTION.

Thematic network. The thematic network of this period (see Figure 5) continued to show the high centrality and density of HEART-RATE. As in the previous period, HEART-RATE showed a complex network of internal and external connections. Internally, it showed strong connections with keywords describing cardiovascular and

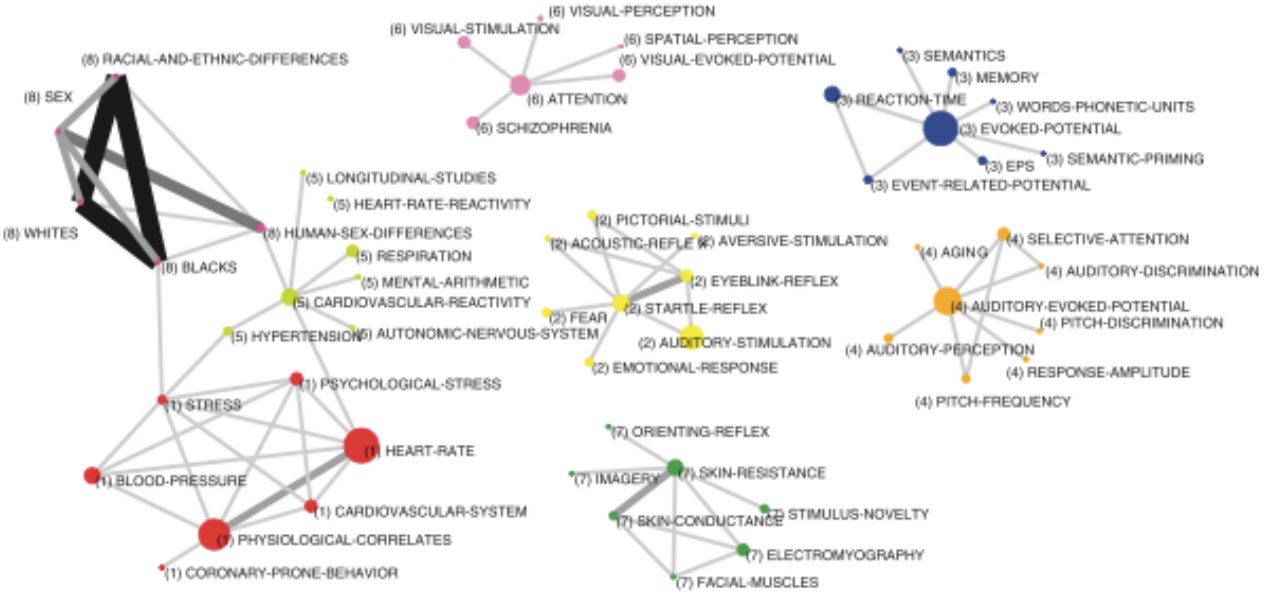

Figure 5. Thematic network of Period 3: 1989–1998.

stress-related concepts. Externally, HEART-RATE had links with two new themes: RACIAL- AND-ETHNIC-DIFFERENCES, which had high density (numerous interconnections with thick lines) in spite of having relatively few articles, and CARDIOVASCULAR-REACTIVITY, which had low density (radial distribution of the keywords). STARTLE-REFLEX is the second motor-theme in this period. Its network showed internal connections with keywords describing stimulus characteristics and emotion-related concepts (aversive-stimulation, pictorial-stimuli, fear, emotional-response). Of the remaining themes, three had networks specifically related to event-related potentials: EVOKED-POTENTIAL, AUDITORY- EVOKED-POTENTIAL, and ATTENTION. Their networks showed low internal and external cohesion. As can be seen in Figure 5, the three themes had predominant radial distribution and no common connecting keywords.

Period 4: 1999–2008.

Strategic diagram. In the last period (879 articles), nine major themes were identified, seven representing physiological measures (EVOKED-POTENTIAL, CARDIOVASCULAR-REACTIVITY/HEART-RATE, STARTLE-REFLEX, ELECTRODERMAL- ACTIVITY, ELECTROENCEPHALOGRAPHY, AUDITORY- EVOKED-POTENTIAL, and PHYSIOLOGICAL-CORRE- LATES) and two representing methodological procedures (VISUAL-STIMULATION and REACTION-TIME). The major motor-theme was EVOKED-POTENTIAL, followed by CARDIOVASCULAR-REACTIVITY/HEART-RATE. EVOKED-POTENTIAL experienced the largest increment in number of articles for all themes in all periods. HEART-RATE decreased in density and centrality as well as in number of articles but remained a motor-theme. STARTLE-REFLEX decreased in number of articles and moved from the upper-right (motor-theme) to the lower-right quadrant (general

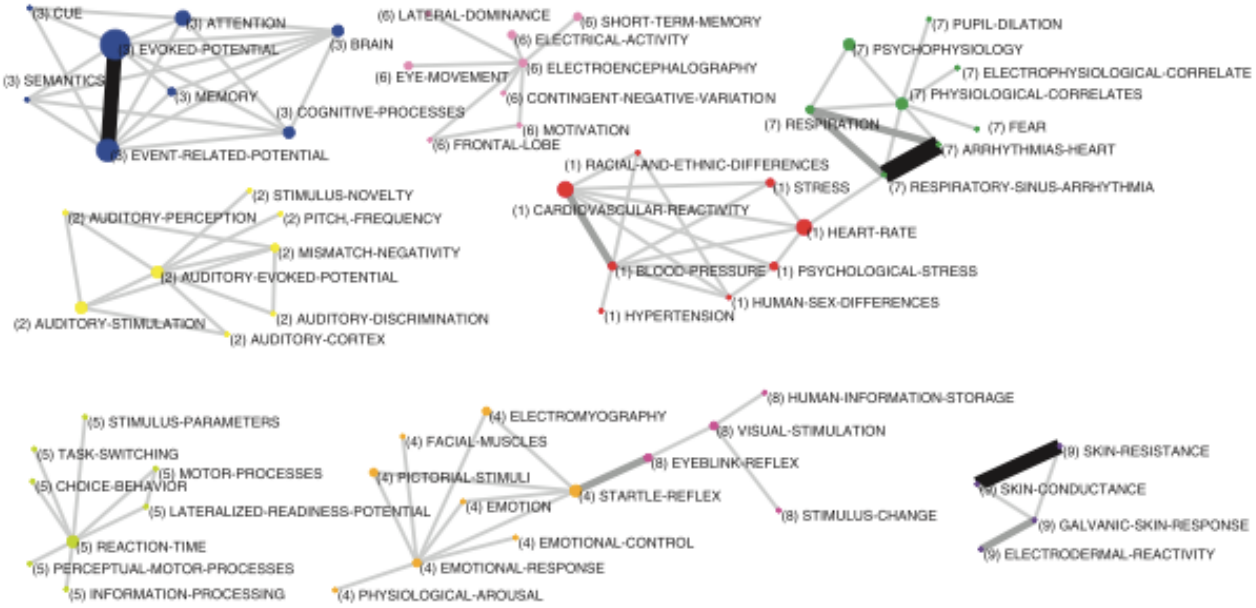

Figure 6. Thematic network of Period 4: 1999–2008.

basic theme), whereas AUDITORY- EVOKED-POTENTIAL increased in centrality but maintained its location near the lower-left quadrant (as an emerging or disappearing theme). Two themes that in the previous period had disappeared, PHYSIOLOGICAL-CORRELATES and ELECTROENCEPHALOGRAPHY, reappeared, and two themes present in the previous period (ATTENTION and RACIAL-AND- ETHNIC-DIFFERENCES) disappeared.

Thematic network. The thematic network of this period (see Figure 6) clearly showed an increase in the number of keywords and interconnections between keywords. EVOKED-POTENTIAL appears as the network with the strongest internal cohesion. It has connection with attention, cognitive-processes, brain, memory, and semantics, all interlinked between themselves. CARDIOVASCULAR-REACTIVITY/ HEART-RATE also showed a strongly interconnected network of keywords de- scribing stress-related concepts and individual differences. Of the remaining themes, only two themes showed external interconnections: PHYSIOLOGICAL-CORRELATES (with CARDIO- VASCULAR-REACTIVITY/HEART-RATE) and VISUAL- STIMULATION (with STARTLE-REFLEX). The new emerging theme, REACTION-TIME, showed a typical low density network (radial disposition) integrated by keywords describing motor and cognitive processes (choice-behavior, task-switching, perceptual-motor-processes) and one specific evoked potential (the lateralized-readiness-potential). Two other themes in this period included in their networks keywords describing specific event-related potentials: AUDITORY-EVOKED-POTENTIAL (the mismatch-negativity) and ELECTRO-ENCEPHALOGRAPHY (the contingent-negative-variation). No specific event-related potential appeared in EVOKED-POTENTIAL.

Discussion

The present results provide interesting insights into some general characteristics of the evolution of the journal Psychophysiology. Although bibliometric maps can be read and interpreted in many different ways, our discussion will concentrate on two specific aspects: first, the dynamics of the strategic diagrams along the four periods and, second, the inner structures of the thematic networks regarding psychological research topics and their relation to physiological variables.

Discussion of the dynamics of the strategic diagrams can be based on five characteristics of the themes: (a) type of central keyword defining the themes, (b) major motor-themes, (c) maintained themes, (d) disappearing themes, and (e) emerging themes.

The central keywords that give their names to the themes can be classified into three categories: physiological, psychological, and methodological. Of the 33 themes appearing in the four strategic diagrams, 73% have a physiological keyword, 18% a psychological keyword, and 0.9% a methodological keyword. The larger percentage of themes with defining keywords of a physiological nature highlights the weight that psychophysiology, as a scientific discipline, gives to physiological measures over psychological research topics and methodological issues.

Several motor-themes appeared in the upper-right quadrant of the diagrams due to their high density and centrality. The largest motor-themes in each period were SLEEP in Period 1 (1964–1978), HEART-RATE in Period 2 (1979–1988), HEART-RATE in Period 3 (1989–1998), and EVOKED-POTENTIAL in Period 4 (1999–2008). HEART-RATE appeared as a motor- theme in all four periods. SLEEP appeared as motor-theme in Periods 1 and 2. EVOKED-POTENTIAL appeared as motor- theme in Periods 2 and 4. Motor-themes that appeared only once were ELECTRODERMAL-ACTIVITY (Period 1) and STAR- TLE-REFLEX (Period 3).

Only three themes in the diagrams were present in all four periods: HEART-RATE, EVOKED-POTENTIAL, and ELECTRO- DERMAL-ACTIVITY. Three themes that were present in Period 1 later disappeared: CLASSICAL-CONDITIONING, BIOFEEDBACK, and ELECTRICAL-ACTIVITY. New themes that emerged after Period 1 followed different evolution patterns. Some themes emerged and were maintained in the periods that followed (AUDI- TORY-EVOKED-POTENTIAL, STARTLE-REFLEX, and CARDIOVASCULAR-REACTIVITY), some emerged and disappeared (AUDITORY-STIMULATION, RACIAL-ETHNIC-DIFFER- ENCES, and ATTENTION), and some emerged, disappeared, and reemerged (ELECTROENCEPHALOGRAPHY and PHYSIOLOGICAL-CORRELATES).

Although the evolving dynamics of the themes over the four periods revealed interesting features of the discipline, they also highlighted some of the limitations of co-word analysis based exclusively on strategic diagrams. One of the major limitations was the selection of the keyword defining the theme. A defining keyword can be selected according to different criteria: centrality, density, or volume. The keyword with the largest centrality, however, does not necessarily coincide with the keyword with the larg-

est density or volume. Moreover, there are different key- words that are clearly synonymous or closely related. Indeed, the lack of homogeneity in the use of key-words is a major problem for bibliometric studies (Kevork & Vrechopoulos, 2009). In

addition, authors may be inclined to choose keywords that distinguish their articles (e.g., new physiological measures versus stable theoretical concepts), thus biasing the data in a way that would overrepresent or underrepresent how methodologically or theoretically oriented the field is.

The limitations of the strategic diagrams can be partly compensated for by a complementary analysis of thematic networks. Thematic networks have their own limitations, especially those derived from the specific thresholds chosen to accept or reject keywords. Depending on the selected threshold, thematic net- works will be larger or smaller, with more or fewer keywords within each theme and with more or fewer internal and external connections between keywords and themes. In our study, the threshold criteria allowed a balanced number of themes within each period (between eight and nine) and keywords within each theme (between four and eight). An overall analysis of the four thematic networks clearly revealed an increase in the number of themes and interconnected keywords in the most recent period (1999–2008), which may suggest a trend toward a richer and more complex discipline.

Our discussion on the thematic networks will focus on three characteristics: (a) specific links between physiological and psychological keywords, (b) evolution of the major psychological research topics across the four periods, and (c) future evolution of the discipline.

The thematic networks showed several specific links between physiological measures and psychological research topics. ELECTRODERMAL-ACTIVITY, for instance, appeared to be specifically linked to orienting-response; HEART-RATE to stress; EVOKED-POTENTIAL to attention, perception and memory; STARTLE-REFLEX to emotion; and ELECTROENCEPHALOGRAPHY to cerebral-dominance. Other physiological measures, such as electromyography, eye-movement, respiration, blood- pressure, pupil-dilation, and temperature, did not show clear associations with specific research topics.

The thematic networks provide some insight into how the major research topics evolved throughout the years. In Period 1 (1964–1978), the major research topics were related to learning processes (classical-conditioning, operant-conditioning, habituation). In Period 2 (1979–1988), the major research themes were motivational in nature (stress, psychological-stress, human-sex- differences). In Period 3 (1989–1998), the primary interest was in cognitive processes (attention, auditory-perception, memory). In Period 4 (1999–2008), the primacy of cognitive processes con- tinued. This thematic evolution parallels changes in psychology from learning and motivation to cognition revealing the strong connection between the two disciplines.

Finally, the thematic network of the latest period also allows some speculation on the future evolution of the discipline. Emotional themes, which experienced an increment

from Period 3 to Period 4, might consolidate and continue growing. Motor processes, which appeared to be integrated in the emerging theme REACTION-TIME, may also experience some future increment and move toward higher density and centrality. Two new keywords, which appeared only in the latest period (brain and frontal-lobe), may suggest the increasing future relevance of neuroscientific and neuroimaging approaches within psycho- physiology.

To our knowledge, this is the first bibliometric study of the journal Psychophysiology based on co-word analysis. The bibliometric study by Holguın and Cadaveira (2003) examined the consolidation of the field between 1930 and 1964, prior to the publication of the journal Psychophysiology. According to Holguın and Cadaveira, this consolidation period was characterized by a predominance of methodological articles, which advanced the standardization of techniques and procedures necessary to support further empirical research. A second bibliometric study by Sanchez-Hernandez et al. (1996) examined the records of the first three decades of the journal Psychophysiology (1964–1993). The authors divided the topics of the articles published by the most productive authors in that period into two different categories: (a) content, for the articles dealing with some specific psychological topic (e.g., attention, stress, etc.) and (b) measures, for those articles whose main focus was the optimal measure of a given psychophysiological response (Sanchez- Hernandez et al., 1996). No data on the evolution of the topics were reported.

The information provided by the bibliometric maps presented in this article complement the previous findings by adding new information and a new perspective. The strategic diagrams and the thematic networks not only identified the major themes of the field, they also provided information about less visible themes and the strength of their interconnections. Moreover, by examining the strategic diagrams across the years, it is possible to recognize specific transient trends that emerged as a result of a technological advancement or theoretical development but that later disappeared or merged with a broader experimental or theoretical context. Such analysis aids understanding of the dynamic structure of a discipline and provides an opportunity to anticipate its future developments.

REFERENCES

Bailon-Moreno, R., Jurado-Alameda, E., & Ruız-Banos, R. (2006). The scientific network of surfactants: Structural analysis. Journal of the American Society for Information Science and Technology, 75, 949–960.

Borner, K., Chen, C., & Boyack, K. W. (2003). Visualizing knowledge domains. Annual Review of Information Science and Technology, 37, 179–255.

Callon, M., Courtial, J. P., & Laville, F. (1991). Co-word analysis as a tool for describing the network of interactions between basic and technological researchFThe case of polymer chemistry. Scientometrics, 22, 155–205.

Callon, M., Courtial, J. P., Turner, W. A., & Bauin, S. (1983). From translations to problematic networks: An introduction to co-word analysis. Social Science Information Sur Les Sciences Socials, 22, 191–235.

Cho, C. H., & Khang, H. (2006). The state of internet-related research in communications, marketing and advertising: 1994–2003. Journal of Advertising, 35, 143–163.

Cobo, M. J., Lopez-Herrera, A. G., Herrera-Viedma, E., & Herrera, F. (2011). An approach for detecting, quantifying, and visualizing the evolution of a research field: A practical application to the fuzzy sets theory field. Journal of Informetrics, 5, 146–166.

Coulter, N., Monarch, I., & Konda, S. (1998). Software engineering as seen through its research literature: A study in co-word analysis. Journal of the American Society for Information Science, 49, 1206–1223.

EC^3 : Research Group ‘‘Evaluacion de la Ciencia y la Comunicacion Cientıfica’’ (2006). CoPalRed (v.1.0) [Software]. Granada: Univer- sity of Granada. Available at http://ec3.ugr.es/.

Echchakoui, S., & Mathieu, A. (2008). Marketing trends: Con- tent analysis of the major journals (2001–2006). Annual Confer- ence of the Administrative Sciences Association of Canada, 29, 114–126.

Holguın, S. R., & Cadaveira, F. (2003). Consolidation of psychophysiology as a scientific discipline, 1930–1964: A historical note. Psychophysiology, 39, 619–624.

Kevork, E. K., & Vrechopoulos, A. P. (2009). CRM literature: Conceptual and functional insights by keyword analysis. Marketing Intelligence & Planning, 27, 48–85.

Leydesdorff, L., & Zhou, P. (2008). Co-word analysis using the Chinese character set. Journal of the American Society for Information Science and Technology, 59, 1528–1530.

Lopez-Herrera, A. G., Cobo, M. J., Herrera-Viedma, E., & Herrera, F. (2010). A bibliometric study about the research based on hybridating the fuzzy logic field and the other computational intelligent techniques: A visual approach. International Journal of Hybrid Intelligent Systems, 17, 17–32.

Lopez-Herrera, A. G., Cobo, M. J., Herrera-Viedma, E., Herrera, F., Bailon-Moreno, R., & Jimenez-Contreras, E. (2009). Visualization and evolution of the scientific structure of fuzzy sets research in Spain. Information Research, 14, paper 421.

Michelet, B. (1988). L’analyse des associations. Unpublished dissertation, University of Paris VII, France.

Sanchez-Hernandez, A., Pedraja, M. J., Quinones-Vidal, E., & Martınez-Sanchez, F. (1996). A historic-quantitative approach to psychophysiological research:

The first three decades of the journal Psychophysiology (1964–1993). Psychophysiology, 33, 629–636.

Whittaker, J. (1989). Creativity and conformity in science: Titles, key-words, and co-word analysis. Social Science in Science, 19, 473–496.

Zhang, J., Wolfram, D., Wang, P., Hong, Y., & Gillis, R. (2008). Visualization of health-subject analysis based on query term co-occurrences. Journal of the American Society for Information Science and Technology, 59, 1933–1947.