Symmetric Non-negative Matrix Factorization for Analyzing the Scientific Production on Day Surgery

Maria Gabriella Grassia, Marina Marino, Rocco Mazza, Agostino Stavolo, and Salvatore Massa

Abstract Operative procedures performed in day surgery are an alternative treatment regimen to ordinary hospitalization, characterized by surgeries that can be performed within the same day, without the need for postoperative observation. These practices are part of a broader process of hospital optimization that has affected the national and international context. Hence, the interest of the work is to identify themes from scientific production through a symmetrical matrix reduction technique, the symmetric non-negative matrix factorization, according to the creation of semantic clusters. The aim is to perform a bibliometric analysis of international and Italian production on day surgery highlighting similarities and differences. In particular, the international production is focused on hospital management and pre- and postoperative conditions for the patient, while the Italian production, based on the treatment of procedures performed in day surgery, especially on older adults' patients.

Keywords Symmetric Non-Negative Matrix Factorization · Day surgery · Topic modeling

M. G. Grassia · M. Marino · A. Stavolo (✉)
Department of Social Sciences, University of Naples Federico II, Naples, Italy
e-mail: mariagrabriella.grassia@unina.it; marina.marino@unina.it; agostino.stavolo@unina.it

R. Mazza
Department of Political Sciences, University of Bari Aldo Moro, Bari, Italy
e-mail: rocco.mazza@uniba.it

S. Massa
AORN Sant'Anna e San Sebastiano Caserta, Caserta, Italy
e-mail: salvatore.massa.mc27@ce.omceo.it

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1 Introduction

Day surgery has become increasingly prevalent worldwide, with more than half of surgical procedures being performed in this manner in many European and North American countries (Toftgaard, 2009). This approach offers an alternative to traditional hospitalization, allowing for a diversified range of healthcare options and contributing to overall facility efficiency. Day surgery is suitable for invasive and semi-invasive procedures that can be safely completed within a single day, considering factors such as complexity, duration, risk of complications, and the patient's condition. It eliminates the need for prolonged postoperative observation. Compared to inpatient surgery, day surgery offers several advantages. Patients can be discharged earlier, promoting earlier mobilization, and reducing the risk of venous thromboembolism (Rajala et al., 2018) and hospital-acquired infections (Darwin, 2016). Additionally, it provides a cost-effectiveness advantage by reducing surgical waiting lists and minimizing the occupancy of hospital beds (Gilmartin, 2007).

Since day surgery patients are responsible for managing their postoperative recovery at home (Dahlberg et al., 2019), it is crucial to provide comprehensive and understandable information as part of the perioperative process to both the patients and their family members (Larsson et al., 2022). This ensures that patients have the necessary knowledge and skills for a successful recovery and self-care, ofteninvolving specific pathways and training programs (Allvin et al., 2007).

The clinical, economic, and social advantages associated with particularly safe procedures and low mortality rates (Gilmartin, 2007) as well as advances in diagnostic and therapeutic technologies have led to an increase in the use of day surgery and ambulatory surgery procedures. This is due to the application of organizational models that have among their main objectives the efficient management of resources to make the best use of available health services (Franco, 2004).

Also, in Italy, one of the main objectives of health system managers is to evaluate and monitor the organizational appropriateness of transferring certain surgical procedures from ordinary hospitalization to different healthcare solutions (Saia et al., 2013). During the last 20 years, surgery in Italy has undergone significant developments in healthcare services at the practice teaching and organizational levels. Ambulatory surgery practices began in Italy in 2002 in line with the optimization practices prescribed by the 1998–2000 National Health Plan regarding the efficient use of resources through alternative forms of patient care. The National Health Service, as indicated in the agreement of the State-Regions Conference of 2002 "Guidelines for day surgery activities," guarantees, as part of day surgery activities, the scheduled performance of procedures requiring the use of the operating room, such as adeno-tonsillectomies arthroscopic surgeries, hernia repairs, and lower extremity varicose.

In this context, our chapter focuses on the evolution of the scientific debate on the topic of day surgery, which has evolved in multiple directions. Recent decades have seen an increasing focus on the study of scientific literature related to a

specific research domain, thanks to the easier availability of online databases and the development of automated tools capable of performing increasingly accurate analyses. Once a research domain has reached a certain degree of maturity, scholars focus their attention on the literature generated by the relevant scientific community (Di Cosmo et al., 2021). Based on this, bibliometric analysis helps to describe the general history and state of the art of a specific research field or topic (Aria et al., 2020), considering written production as the main means of communication among scientists (Bellardo, 1980). In this regard, we have defined the main topics on which this evolution has been observed. These practices are part of a broader process of hospital optimization that has affected the national and international context (Massa et al., 2022). For this reason, the contribution involves the use of Symmetric Non-negative Matrix Factorization (SymNMF) to create semantic clusters to identify the main themes of scientific production, identifying similarities and differences between Italian and international production.

2 Symmetric Non-negative Matrix Factorization

Non-negative Matrix Factorization (NMF) was first introduced by Paatero and Tapper (1994) as a concept for factoring positive matrices. It became better known as NMF when Lee and Seung (1999) highlighted the potential value of part-based representation (Wang & Zhang, 2012). Subsequently, the NMF gradually became an attractive multidimensional data processing tool for many researchers because of its ability to provide a simplified interpretation of results made possible by the non-negativity constraint. Specifically, NMF is a dimension reduction method for discovering low-dimensional latent structures in high-dimensional data (Kim & Park, 2008), in which factor matrices are constrained to have only non-negative elements (Kuang et al., 2015). Therefore, the matrix basis vectors are represented as a linear combination of vectors with positive coefficients. The non-negativity condition differs from dimensionality reduction techniques based on the Singular Value Decomposition (SVD) method, such as Principal Component Analysis (PCA) in that the basis vectors have positive and negative components (Pauca et al., 2004), implying the presence of some negative values. On the other hand, the factors obtained from the NMF have positive vectors and better approximate the data, but they are not necessarily orthogonal (Casalino et al., 2016).

In recent years, NMF has received more attention in machine learning and text data mining research (Pauca et al., 2004; Yan et al., 2013), for blind source separation (Virtanen, 2007), intrusion detection (Guan et al., 2009), video and image processing (Salehani et al., 2020), and clustering (Liu et al., 2013). However, NMF is not a clustering method that can be applied in all conditions as it is affected by cluster structure (Kuang et al., 2015). For this reason, SymNMF, the symmetric variant of NMF, based on a similarity measure between data points, factorizes a symmetric matrix $\mathbf{A}$ into the product between the cluster assignment $\mathbf{H}$ and its transpose $\mathbf{H^T}$: $A \approx HH^T$ (Jia et al., 2021).

The formulation of SymNMF $min_{H \geq 0} \mid |A \approx HH^T| \mid {}^2{}_F$, can be related to a generalized form of many clustering objectives (Kuang et al., 2015), where **H** is a non-negative matrix of size $n \times k$, and k is the number of clusters required. Underlying this is the idea that points in the same cluster have high similarity values and points that are in different clusters have low similarity values. This leads us to say that a good approximation of the matrix **A** catches the structure of clusters, considering the largest entry in the *i-th* row of **H** indicates the clustering assignment of the *i-th* data point due to the constraints of non-negativity of **H** (Kuang et al., 2012).

SymNMF outperforms NMF when dealing with non-linearly separable data. Jia et al. (2021) demonstrated the effectiveness of SymNMF as a powerful method for clustering data, while Yan et al. (2013) highlighted its efficacy in extracting arguments from lexical matrices. Although SymNMF is conceptually like spectral clustering, recent studies, such as Vangara et al. (2021), have shown that SymNMF performs better than both k-means and spectral clustering methods. Moreover, Kabir et al. (2020) illustrated how SymNMF transforms spectral clustering into an optimization problem with stationary point solutions. Additionally, SymNMF has been successfully applied in community detection within graphs (Luo et al., 2021).

3 Data and Materials

According to the academic license to WoS collection, the bibliometric analysis was executed from January 2002 to December 2022 including scientific products reported in the Web of Science (WoS) database. All publications of interest were identified by using the following query TS = ("day surgery") in title, abstract, author keywords, and keywords plus. The system returned 2693 papers. We extracted abstracts of articles, proceedings papers, and review articles. We refined our search by selecting the categories included under the paragraph "Guiding an illustrative list of surgeries and surgical procedures that can be performed in day surgery as an alternative to ordinary hospitalization," contained within the guidelines for day surgery activities. The search protocol was then refined by selecting through the following WoS categories: Surgery, Cardiac Cardiovascular System, Medicine General Internal, Oncology, Orthopedics, Clinical Neurology, Gastroenterology Hepatology, Respiratory System, Peripheral System, Pediatrics, Ophthalmology, Urology Nephrology, and Anesthesiology. The next refinement was to select only articles and reviews in English. Then, we obtained our final collection of 1742 items for international production.

We analyzed the Italian scientific production in the field of day surgery using the same categories provided by WoS for international literature. Additionally, we determined the scientific output of authors affiliated with institutions in Italy by utilizing the "Country/Region" category in WoS. We achieved a database composed of 194 documents. Table 1 reports the percentage of documents belonging to the

Table 1 Percentage WoS Categories for international and Italian documents

Categories	% International doc	% Italian doc
Surgery	37.7%	51.6%
Anesthesiology	22.3%	11.1%
Medicine general	11.2%	7.2%
Pediatrics	7.6%	7.7%
Orthopedy	5,1%	1.1%
Urology	4.4%	6.1%
Clinical neurology	4.2%	2.2%
Gastroenterology	4.2%	6.6%
Vascular disease	1.6%	5%
Oncology	2.7%	7.2%
Cardiovascular system	0.8%	1.1%
Respiratory systems	0.5%	0%
Total	100%	100%

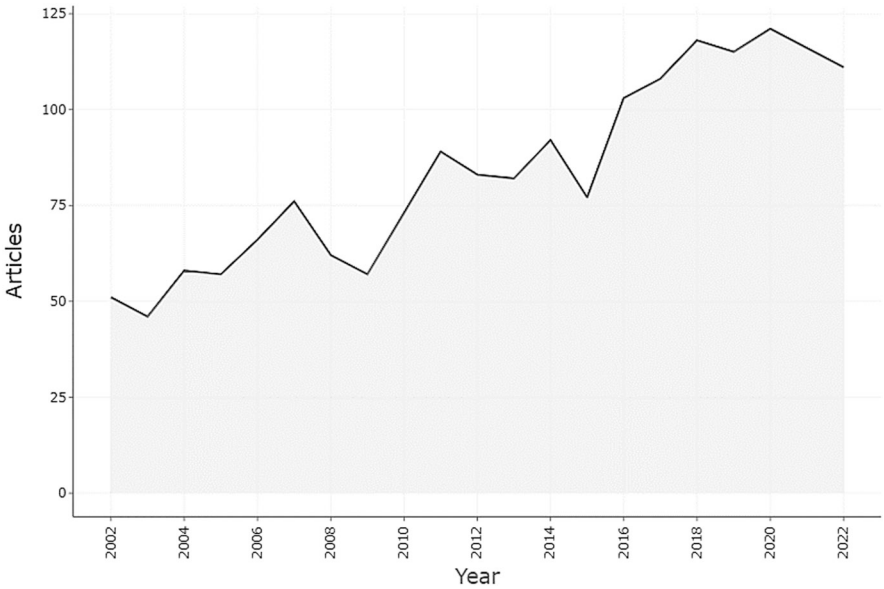

Fig. 1 Annual international scientific production

respective categories of WoS. Most Italian scientific production comes from the "surgery" category (51.6%), while international production also shows high values for anesthesiology (22.3%) and general medicine (11.3%).

All the descriptive analyses shown in the following were conducted with the open-source R package *bibliometrix* (Aria and Cuccurullo 2017).

Figures 1 and 2 show, respectively, the time trend of international and Italian scientific production over the two decades considered. This leads us to consider that the production of scientific articles is mainly concentrated in the last 6 years since

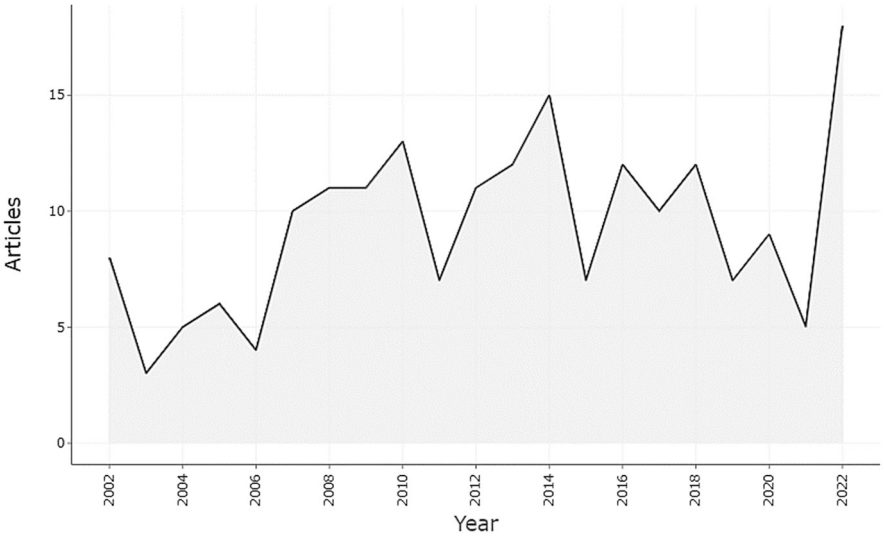

Fig. 2 Annual Italian scientific production

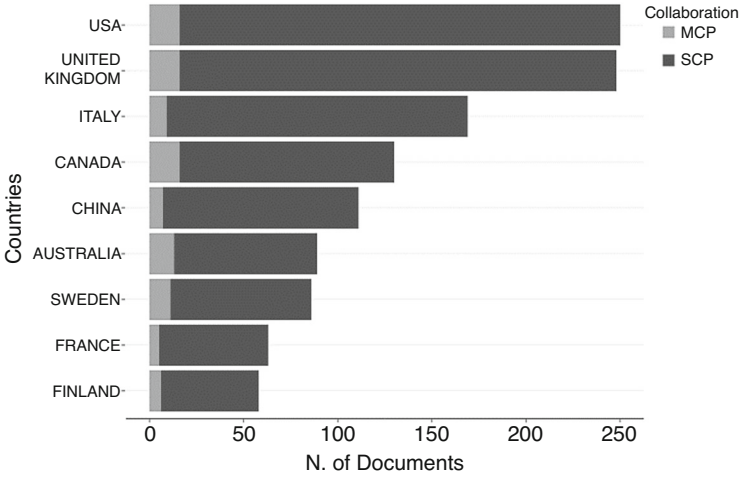

Fig. 3 Corresponding author's country

2016 showing an annual growth rate of 4.7%. As for Italian production, on the other hand, there is a high peak in the 2 years 2012–2014, which comes to be reconfirmed in 2022.

Figure 3 shows information about the production of the first 10 countries ordered by the total number of publications by corresponding authors. Specifically, Single Country Publications (SCP) represents the number of articles in which all authors belong to the same country, while Multiple Countries Publications (MCP) is defined

by the number of articles including at least a co-author working in a different country to the corresponding author. We noted that English-speaking countries such as the UK and the USA, have a higher number of contributions published by local authors. Italy, in third place, has a low value of publications with authors other than the primary author, indicating a trend toward producing content in the national context. This could explain the significant differences that emerged in the later stages of this research, as a possible consequence of the low rate of exchange of scientific knowledge due to poor forms of international co-authorship.

4 Main Results

Documents undergo a process of parsing and tokenization, which results in a set of distinct strings (tokens) separated by spaces, punctuation marks, or other special characters. The schema obtained through tokenization is known as a Bag-of-Words (BoW), as it treats each document as a multiset of tokens, without considering grammatical and syntactic roles. Once the documents have been "atomized" into their basic components, pre-processing steps were necessary to reduce linguistic variability (Uysal & Gunal, 2014). To ensure consistency among different language variants, normalization procedures were implemented, such as correcting misspelled terms, modifying word accents, and removing numerical characters (Misuraca & Spano, 2020). The process of grammar tagging was considered, which allows assigning each term its respective Parts of Speech (POS), identifying nouns, adjectives, and verbs for vocabulary construction. This phase proved to be crucial because it enabled the recognition of POS that are functional in identifying word categories. Subsequently, lemmatization was performed, where each term was brought back to its canonical form: verbs were conjugated to the present infinitive, while nouns and adjectives were in the masculine singular form. Once the documents were pre-processed, the so-called vocabulary was constructed, recording for each term the number of occurrences of each term (type) in the document collection. From the list of terms in the vocabulary, stop words (such as prepositions, conjunctions, adverbs, etc.) were removed to ensure that the remaining terms were meaningful topics. The pre-processing phase returned a database for international production composed of 146,178 tokens, 12,825 types, and 1742 documents. So, the term-document matrix, which indicates the number of occurrences of each term in the document, is 12,8250x1742. For Italian scientific production, the database is composed of 18,257 tokens, 4246 types, and 194 documents: thus, the term-document matrix is 4246x194.

In the final stage of the pre-treatment process, the vector space model was applied to the terms-document matrix. We can consider each term as a vector in which generic element w_{ij} represents the weight of each word within the individual document, defining the number of times the term is present within the single document. This weighting system leads to the creation of an overly sparse matrix. In the case of the NMF, the term-document matrix is so sparse that it is not possible

Table 2 International semantic clusters

Cluster 1	Cluster 2	Cluster 3	Cluster 4
Child	Government	Postoperative	Background
Father	Focus	Headache	Body
Mother	Demand	Safety	Association
Emotional	Development	Symptom	Arterial
Distraction	Cost	Requirement	Blood
Parent	Policy	Pain	Antiemetic
Game	Fund	Anesthesia	Benefit
Distress	Healthcare	Treatment	Cardiovascular
Stressful	Efficiency	Nausea	Effect

Table 3 Italian semantic clusters

Cluster 1	Cluster 2	Cluster 3
Harm	Safety	Cost
Infiltration	Treatment	Drug
Operation	Postoperative	Complication
Cholecystectomy	Pain	Elderly
Effect	Anesthesia	Evaluate
Laparoscopy	Factor	Hernia
Anxiety	Risk	Veins
Diagnosis	Care	Cataract
Local	Safe	Cancer

to create reliable themes. According to Yan et al. (2013), to reduce the sparsity of the term-document matrix, we created a co-occurrence matrix C composed of the vectors $c_{ii'}$, whose generic elements $a_{ii'}$ represent the number of times each word pair $<c_i, c_{i'}>$ co-occurs in the same document. For each pair of term vectors, we constructed a similarity matrix S by calculating the cosine measure, which measures the similarity between two vectors of an inner product space. SymNMF was applied to the similarity matrix S to create semantic clusters. From here, we were able to define four clusters for international scientific production (Table 2) and three clusters for Italian production (Table 3).

The first cluster identifies day surgery treatment of children and young patients. International scientific production focuses on psychological strategies that reduce children's anxiety (Meng & Zastowny, 1982). However, the responsibility for preparing children for same-day hospitalization falls on parents (Ellerton & Merriam, 1994). There is a strong focus on preoperative treatment, to calm the patient and make him less emotionally stressed, and in the postoperative period, paying special attention to the symptomatology that develops before returning home. The latter condition is related to the second cluster that focuses specifically on the postoperative course and the critical issues that develop in symptomatology, such as "headache" and "nausea." Also emphasized is the topic of postoperative "pain" and related strategies to improve patients' conditions, such as "anesthesia." The third cluster, on the other hand, focuses on the importance of creating investments in health care to improve the efficiency of facilities and interventions. These funds

represent an important opportunity to improve the health of citizens and ensure that services meet the needs of patients. The last topic addressed is the baseline situation before the operation, which allows physicians to assess whether the patient's condition is suitable for undergoing surgery. This assessment is crucial in determining the patient's eligibility for the procedure and evaluating the potential risks or complications associated with their specific health condition.

Italian production is focused specifically on treatments and types of operations that are performed in day surgery. Two specific examples mentioned are laparoscopy and cholecystectomy. Laparoscopy is a minimally invasive surgical technique that allows surgeons to perform operations through small incisions using a camera and specialized instruments. Cholecystectomy, on the other hand, refers to the surgical removal of the gallbladder. As shown in the second cluster, there is a strong focus on postoperative consequences that become central to the discussion, but the subject of the operations becomes the older adults' patients. The literature on the subject is, in fact, focused on the different modalities and drugs with which anesthesia can be performed to ensure greater safety and the fewest problems upon awakening. Anesthetists have access to improved aesthetic agents that have minimal after-effects such as drowsiness, nausea, and vomiting (Rhodes et al., 2006). In addition, the surgical treatment of some surgeries such as cataract, varicose veins, and inguinal hernia operations are strongly evident. Inguinal hernia is more frequent in older adults than in younger patients because of loss of strength of the abdominal wall and conditions, which increase intraabdominal pressure (Amato et al., 2013). It is one of the most common surgical procedures, with good results and minimal morbidity, and is usually performed on an outpatient basis unless coexisting medical conditions merit hospitalization (Kingsnorth & LeBlanc, 2003).

5 Discussion and Conclusion

International production on day surgery places a strong emphasis on implementing psychological strategies aimed at reducing anxiety in children and young patients. The focus lies on ensuring effective psychological preparation and care to create a calming environment for these individuals. In contrast, Italian production tends to concentrate more on specific surgical procedures and anesthesia modalities, particularly in relation to the older adult population. The research in Italy recognizes the unique challenges and considerations that arise when administering anesthesia and providing postoperative care to older patients.

Regarding patient demographics, international research primarily centers around day surgery treatment for children and young patients. The studies highlight the importance of addressing the specific needs of this age group to ensure successful outcomes. On the other hand, Italian research tends to prioritize the treatment of the older adult population in day surgery, given the distinct factors associated with their care, such as anesthesia administration and postoperative monitoring. Specifically, Italian production places significant emphasis on postoperative consequences,

delving into the symptomatology that may arise and the use of anesthesia agents with minimal after-effects. This focus reflects the aim of optimizing patient comfort and well-being during the recovery phase.

It is crucial to note that these observations are based on the provided information and may not encompass the entirety of international and Italian production on day surgery. Additionally, the field of day surgery research is extensive, and there may be other factors, perspectives, or variations within the literature that are not fully represented in the given context. Our study contributes to the field of bibliometric analysis, a methodology that offers insights into the main themes of scientific production in various medical disciplines, including radiology, cardiology, endocrinology, and infectious diseases. This work serves as an alternative to other bibliometric techniques such as co-occurrence networks and thematic maps. We chose to employ SymNMF as our analysis technique due to its ability to perform more precise clustering operations compared to traditional methods like k-means and spectral clustering. One of the key challenges in clustering methods is determining the appropriate number of clusters within the data. In future developments, we aim to refine the process of defining the number of clusters to be extracted, considering various approaches outlined in the existing literature (Vangara et al., 2021).

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