Altmetrics for the identification of scientific controversies: The case of *NeuroGenderings* and neurosexism

María Aguilar-Soto; **Nicolás Robinson-García**; **Benjamín Vargas-Quesada**

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Recommended citation:

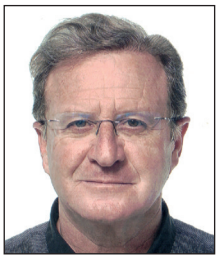
Aguilar-Soto, María; **Robinson-García, Nicolás**; **Vargas-Quesada, Benjamín** (2023). "Altmetrics for the identification of scientific controversies: The case of *NeuroGenderings* and neurosexism". *Profesional de la información*, v. 32, n. 6, e320610.

https://doi.org/10.3145/epi.2023.nov.10

Article received on October 4th 2023
Approved on November 16th 2023

María Aguilar-Soto
https://orcid.org/0000-0002-8772-8832

Universidad de Granada
Unit for Computational Humanities and Social Sciences
Colegio Máximo de Cartuja, s/n
18071 Granada, Spain
m_aguilar@ugr.es



Benjamín Vargas-Quesada
https://orcid.org/0000-0001-5115-7460

Universidad de Granada
Unit for Computational Humanities and Social Sciences
Colegio Máximo de Cartuja
18071 Granada, Spain
benjamin@ugr.es

Nicolás Robinson-García ✉
https://orcid.org/0000-0002-0585-7359

Universidad de Granada
Unit for Computational Humanities and Social Sciences
EC3 Research Group
Colegio Máximo de Cartuja, s/n
18071 Granada, Spain
elrobin@ugr.es

Abstract

This work presents a methodological proposal for the analysis of social controversies related to scientific literature. This methodology consists of three clearly differentiated parts. First, we identify the cognitive structure of a set of scientific works. To do this, a historiogram is created through the analysis of references cited by seminal works. This allows us to expand the set of works to work with, subsequently conducting a co-word analysis to identify the cognitive structure of the scientific field to be explored. Secondly, we obtain social mentions of this scientific literature using so-called altmetrics. This allows us to extract mentions made to each scientific document from non-academic environments. Finally, we apply sentiment analysis techniques to these mentions to identify focal points of negative sentiment. We test this methodology on the case study of *NeuroGenderings*, a movement in the field of neuroscience that denounces the lack of scientific evidence in works that claim the existence of brain differences driven by the biological sex of the subjects. Our results confirm the viability of these types of approaches that enable the identification of research areas with greater controversy. Although our study is limited to the analysis of controversies in news, blogs, *Facebook*, *Wikipedia*, and *Reddit*, the methodology can be applied to other domains and social platforms.

Keywords

Neurosexism; Scientific controversies; Altmetrics; Sentiment analysis; News; Blogs; Social media; *Wikipedia*; *Reddit*; *Facebook*; Science mapping; Neuroscience; Gender; Sex; *Neurogenderings*.

Funding

This work has been financed by the Spanish *Ministry of Science and Innovation*, reference MCIN/AEI /10.13039/501100011033, and by the European Social Fund "*FSE invierte en tu futuro*".

Nicolás Robinson-García is a Ramón y Cajal researcher (REF: RYC2019-027886-I).

1. Introduction

Controversy is an inherent part of generating scientific knowledge. Both **Kuhn** (1962) and **Popper** (1959), leading proponents of two entirely contrasting views on scientific development, consider controversy a key issue for achieving such progress. Within the field of bibliometrics, highly explored areas are the structure of scientific knowledge (**Scott**, 1988; **Wasserman**; **Faust**, 1994), the analysis of scientific domains (**Boyack** *et al.*, 2009; **Vargas-Quesada** *et al.*, 2010a), and information visualization (**Vargas-Quesada**; **De-Moya-Anegón**, 2007). Such studies confirm the hierarchized structure of science, where different disciplines are organized based on the level of internal consensus (**Cole**, 1983; **Fanelli**; **Glänzel**, 2013).

However, identifying controversy for bibliometric purposes remains largely unresolved. There are few bibliometric proposals surrounding disagreements in science, and most are limited to using lists of words as markers of controversy (**Lamers** *et al.*, 2021) or training deep learning classifiers with a corpus of texts already encoded as controversial or not (e.g., **Nicholson** *et al.*, 2021).

An alternative approach comes from the emergence of altmetrics (**Priem** *et al.*, 2010; **Torres-Salinas** *et al.*, 2013): a battery of indicators related to the online environment but expanded over time to all kinds of indicators, beyond the traditional notion of scientific impact measured through citation, allows for the measurement of social impact (**Thelwall**, 2020). Accordingly, the indicators offer a means of detecting controversy in science —that is, works that are highly discussed and debated in social networks. Following a somewhat different approach, **Van-Schalkwyk, Dudek,** and **Costas** (2020) explore controversy in science by applying network analysis to Twitter users and their views regarding vaccination. A more qualitative approach is that of **Nane** *et al.* (2021), who look at the use of scientific evidence in public debates following the Covid-19 pandemic.

The present study aims to further explore the potential of altmetrics for appraising controversies in science. We focus on the specific case of *NeuroGenderings*, a neurofeminist movement within the field of neuroscience, challenging certain axioms about sexual biological determinism affecting people's gender. To do so, we combine more traditional approaches with enriched altmetric treatment of content. At the core of this movement, the *NeuroGenderings* network (*https://neurogenderings.org*), reflects scientific influences, points of dissent with the mainstream, and contributions to the debate on sexual/gender differentiation.

Below, we briefly describe the selected case study, its origin, and development. We then describe the dataset used, as well as the bibliometric techniques employed. Section 4 offers the results of our analysis, which are subsequently discussed. We conclude by addressing certain implications of work involving altmetric techniques to analyze controversies in science.

2. Case study: The *NeuroGenderings* network

On August 22, 2022, amid the rise of the *Trans Law*, the professor and feminist philosopher Judith Butler received the Gold Medal from the *Círculo de Bellas Artes* in Madrid. Butler is an advocate of queer theory, claiming that sexual or gender identity does not correspond to established rules regarding sexuality and gender. This theory has permeated research fields such as neuroscience, giving rise to gender neuroscience. Essentially, sexual differentiation is put into question. Having emerged in the 1970s, this theory asserts that the brain´s exposure to certain hormones before birth determines biological sex. Sexual differentiation is therefore based on the existence of "original" sexual differences between men and women (**LeVay**, 1991), or sexual biological determinism (**Jordan-Young**; **Rumiati**, 2012). This implies a sexual dimorphism of the human brain, and behavioral differences inherent to biological sex that determine gender roles (**Jordan-Young**; **Rumiati**, 2012; **Kaiser**, 2012; **Kaiser** *et al.*, 2009).

In the 1990s, this approach was questioned, accused of being unscientific and unethical, positioning individuals of one sex above the other, both socially and in economic or political spheres (**LeVay**, 1991). The existence of discrete categories of men and women remains challenged (**Jordan-Young**; **Rumiati**, 2012; **Oudshoorn**, 1994), as do the link between biological sex and gender (**Kaiser**, 2012; **Kaiser** *et al.*, 2009), and biological determinism (**Jordan-Young**; **Rumiati**, 2012). As a result of this debate, in 2010, the first international and transdisciplinary workshop of neurofeminist academics materialized: the *NeuroGenderings* network aimed to review neuroscientific production and develop a series of theoretical and empirical approaches for gender neuroscience research.

An article published in 2017 refers to *NeuroGenderings* as "epistemological guerrillas" within "feminist epistemologies". The objective would be to improve science through an objective attempt to eliminate biases in research based on "sexual differences in the brain," separating scientific research from pseudoscience, which uses alleged empirical evidence to justify an inequality intended to be "natural" (**Reverter-Bañón**, 2017).

In addition to contextualizing *NeuroGenderings*, this article mentions an important fact detrimental to feminist neuroscience: given the variable impact of biological sex in mental disorder-related research, the journal *Neuroscience Research* began to require the presence of this biological variable in all studies to be published from 2017 onwards. This policy prompted constructive criticism from *NeuroGenderings*, pointing out the danger and consequences of using biological sex as a reference and the possibility of fomenting bias in research, when other variables might be more determinant (**Rippon** *et al.*, 2017).

3. Materials and methods

Our work puts forth a combination of bibliometric and altmetric techniques, combined with sentiment analysis to identify controversies in science. We adopt an exploratory focus, on the case study of the *NeuroGenderings* movement. The analysis has three stages. First, the epistemological roots of the *NeuroGenderings* movement are analyzed through reference analysis. Next, we look at contributions directly provided by this movement to understand how it may differ from other contributions. Then we extract all mentions of *NeuroGenderings* movement works identified in different social networks and media, to identify areas of controversy. In addition, we describe the data collection process, data processing, and methodological design.

3.1. Data collection and processing

The seminal data was collected from the website *https://www.neurogenderings.org*, in September 2021. There are 120 documents (Annex I: *https://zenodo.org/doi/10.5281/zenodo.10141723*).

To determine the origin of *NeuroGenderings* knowledge, we ran a search in the *Web of Science* (*WoS*) database by DOI and ISBN, identifying 45 documents indexed. After downloading the records as well as their references (137), we obtained a total of 182 documents (Annex II: *https://zenodo.org/doi/10.5281/zenodo.10141723*) that serve as the basis for our epistemological analysis of the movement.

As a preliminary step of altmetric analysis, we conducted a web reputation audit using the names of the members of *NeuroGenderings*. Reputation is a general indicator of quality, visibilization, and how an organization is perceived and judged by individuals (**Griffin**, 2008). The results of the first 10 searches on a search statement, representing the object of study, are analyzed. Content analysis considers the reliability and accuracy of the information according to the place where it is hosted, thus reflecting a positive or negative image of the components of *NeuroGenderings*.

Table 1. Document type of the *NeuroGenderings* seminal data

Typology	Nº
Books	27
Book chapters	15
Articles	72
Other categories (journalistic articles, popular science magazines, blog entries…)	6
Total	120

All altmetric mentions related to our set of documents were extracted through Altmetric.com, a main altmetric provider (**Robinson-García** *et al.*, 2014). To do this, we again began with the total collection, identifying 71 documents indexed in Altmetric.com, of which 56 had at least one mention.

3.2. Methodological design

Seminal documents or *milestones* in scientific literature tend to be highly cited (**Muñoz-Écija** *et al.*, 2017). Therefore, we applied the Citation-Assisted Background technique (**Kostoff**; **Shlesinger**, 2005) for their detection, using *CitNetExplorer* software (**Van-Eck**; **Waltman**, 2014). This software creates a historiogram that clusters documents according to their citation links, revealing their intellectual structure and main research fronts.

Taking the bibliographic fields Authors Keywords (AK) and Keywords Plus (K+) as the unit of analysis (**Muñoz-Écija** *et al.*, 2019; **Vargas-Quesada** *et al.*, 2017), we created a co-word map based on the occurrences of each term pair (**Callon** *et al.*, 1983). This map became the basic representation of the network or cognitive structure of our dataset. The network was configured using *VOSviewer* visualization software (**Van-Eck**; **Waltman**, 2010). To detect the main lines of research, we applied the Leiden community detection algorithm (**Traag**; **Waltman**; **Van-Eck**, 2019), and the results were subsequently validated by two independent experts (in the fields of Psychology and Neuroscience).

Said validation consisted of the manual review of the terms assigned to each of the clusters as well as the description of each of them, determining the topics on which they were focused.

The map served as a basis to overlay specific aspects of cognition such as alterations or novelties in the structure (**Leydesdorff**; **Ràfols,** 2012; **Muñoz-Écija** *et al.*, 2022). To clean and control the keywords, an *ad hoc* thesaurus was built, normalizing singular and plural forms, abbreviations, and synonyms (Annex III: *https://zenodo.org/doi/10.5281/zenodo.10141723*).

To detect scientific controversies, we analyzed the mentions received by our dataset on different social networks. Specifically, we focused on mentions from *Wikipedia*, *YouTube*, blogs, *Reddit*, and *Facebook*. These sources were selected not only for their interest in capturing potential scientific controversies

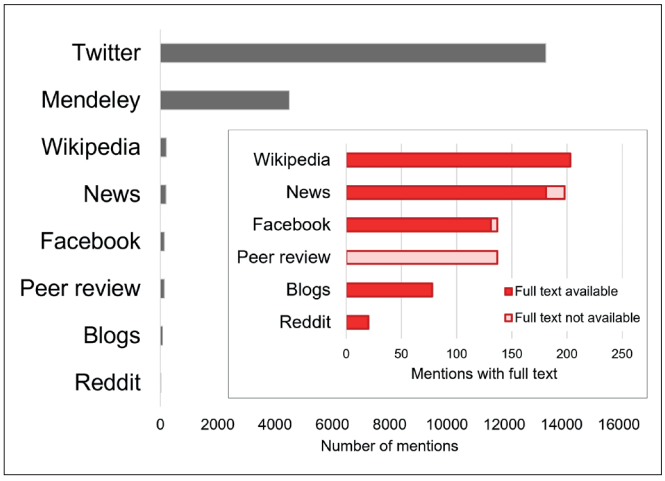


Figure 1. Number of mentions identified per platform and number of mentions including the full text on *Altmetric.com*.

but also for the level of accessibility they allow, as shown in Figure 1. The platform *X* (former *Twitter*) was excluded from our study because of its recent policy changes **Arroyo-Machado**, 2023). Once all mentions were extracted, we automatically translated those appearing in a language other than English using the statistical software *R* v. 4.3.1 (*R Core Team*, 2023) and the *deeplr* package (**Zumbach**; **Bauer**, 2022).

Sentiment analysis was performed with the SentimentAnalysis package (**Proellochis**; **Feurriegel**, 2021). It combines natural language processing (NLP) techniques and keyword dictionaries to assess the emotional polarity of text lines, assigning each text line a value between -1 and 1 (-1 being the extreme value assigned to text reflecting a negative sentiment, and 1 being the extreme value assigned to a positive sentiment). This allowed us to categorize mentions in three groups: negative (value < 0), neutral (value = 0), and positive (value > 0). Sentiment analysis was conducted on two levels. First, an altmetric source analysis helped identify which reflected greater emotional polarity. A second analysis was performed at the cluster level, based on the thematic blocks identified in the cognitive map underlying the *NeuroGenderings* movement.

4. Results

4.1. Intellectual and cognitive structure of *NeuroGenderings*

NeuroGenderings rely on a comprehensive review of articles to reveal bias in the search for differences between sex/gender and to reconsider neuroscientific methodology. From this perspective, the lack of scientificity regarding the theory of sex difference and its unethical nature would necessitate a revision of Neuroscience and the brain-behavior relationship.

Figure 2A displays the cognitive historiogram created from our dataset of 182 documents. Each node represents a work. The lines show the citation relationships and intellectual influence among works. The time scale on the left and correspondence with each node indicate the publication date. The historiogram is therefore a graphic representation of the origin of a particular subject matter or knowledge and its flow over time. The color of the nodes marks the two clusters identified by *CitNetExplorer*. By crossing those works in WoS with their thematic category, we established that those in blue are empirical works based on *Scientific Neuroimaging* (NI), and specifically functional magnetic resonance imaging (fMRI) to understand the interaction between individual neurobiology and the environment, and centered on sex/gender studies. In turn, the green front signals works of a more theoretical-conceptual nature, where the theory of sexual differentiation is criticized. As we are interested in controversy, we focus our analysis on the green cluster.

Although the *NeuroGenderings* movement emerged in 2010, its roots lie in the ideas of the article by **Phoenix** *et al.* (1959), who established the foundations of the theory of sexual differentiation. In the early 1990s, Butler published two books that introduced the purported relationships between sex/gender (**Butler**, 1990) and re-established queer theory (**Butler**, 1993). Queer theory conceptualizes individuals' sexuality as discursive, fluid, plural, and entailing continuously negotiated social constructions. Influenced by Butler, *NeuroGenderings* chose the term sex/gender, considering it inseparable (**Kaiser** *et al.*,

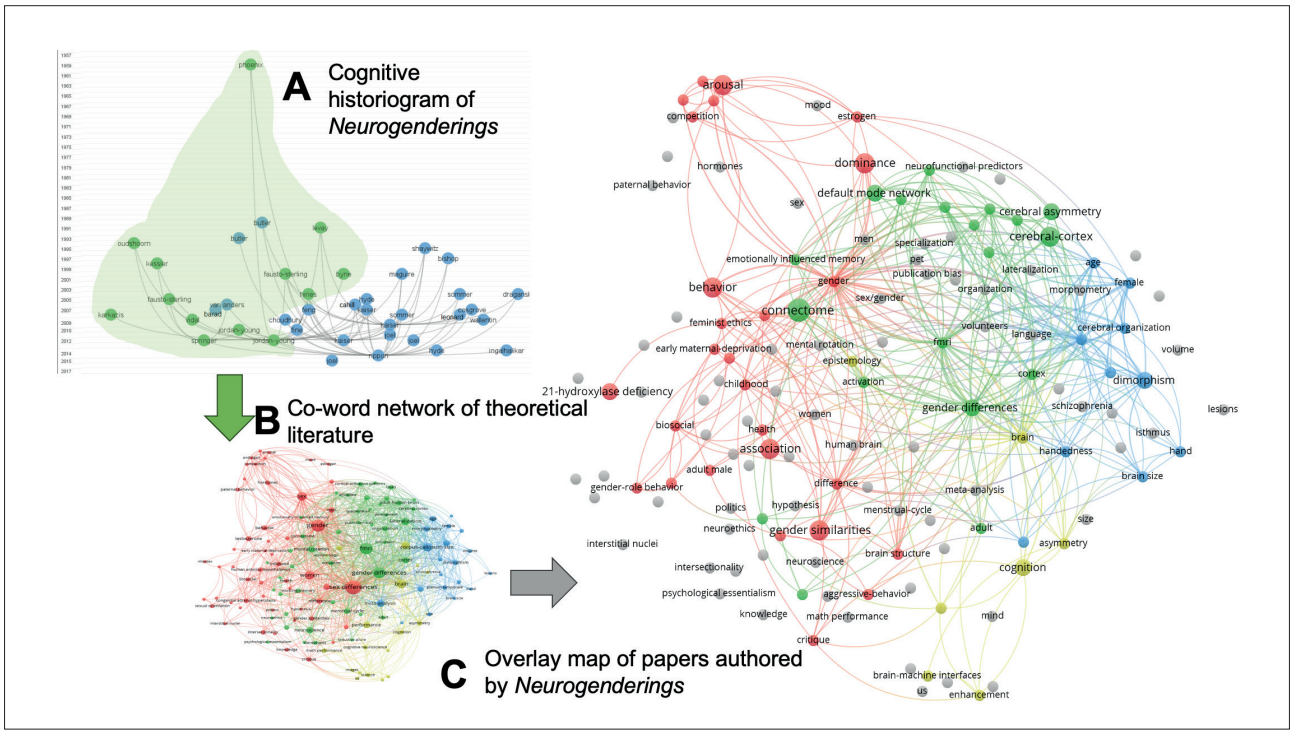


Figure 2. Cognitive historiogram and co-word maps related to the *NeuroGenderings* movement. A) Cognitive historiogram, B) Base co-word map, and C) Co-word map of *NeuroGenderings* works superimposed on the base map. The decomposition of this figure is available in: *https://doi.org/10.5281/zenodo.10141724*

2009), while calling for a revision of the "theory of sexual difference". In the lower left part of the historiogram, connected to Butler owing to their critical perspective, we find five works. The last one defines neurosexism, closing the circle of critical works on science (**Fine**, 2010). To the left of these works, a number are interconnected, the interweaving of sex/gender highlighting that the human brain cannot be categorized solely as that of a man or woman.

In the central right part, we find works dealing with the brain's plasticity and independence from biological sex, as well as others related to brain dimorphism, which *NeuroGenderings* holds to be an example of malpractice and bias. In this same area, we observe other studies addressing differences between sex/gender in language, one aspect of differentiation between men and women. In the lower right area we find works questioning brain dimorphism, concluding that it is actually multiform. This idea is consistent with **Hyde**'s (2005; 2014) work on the similarity hypothesis, surpassing the theory of sexual differentiation (**Kaiser** *et al.*, 2009). Very close to this conceptualization of the similarity hypotheses, to the left, we find *NeuroGenderings'* postulation against the theory of brain organization and its purely biological "hardwiring"(**Jordan-Young**; **Rumiati,** 2012; **Rippon** *et al.*, 2014), to explain male-female behavior.

Figure 2B displays the cognitive structure of *NeuroGenderings*. The nodes represent words, and their size is proportional to the number of times they co-occur in the documents. Links indicate co-occurrence connections between terms, and their proximity is determined by the number of times they co-occur. Colors represent each of the research lines identified by the community detection algorithm. This visualization reveals a specialized and interdisciplinary ecosystem having four lines of research. The central and larger nodes are "sex differences" and "gender", reflecting the theory of sexual differences and its relation to behavior. Many neuroscientific studies on sex/gender differences have been developed through fMRI neuroimaging techniques, hence their size.

Figure 2C shows the co-word map of *NeuroGenderings* (overlaid map), composed exclusively of terms extracted from the 45 original *NeuroGenderings* documents, positioned on the *NeuroGenderings* base map or ecosystem. This representation highlights the presence and contribution of *NeuroGenderings* to research, eliminating terms that are not specific to this group, while displaying only those that are, along with their relationships.

Table 2. Main lines of research

Color	Research lines	Number of nodes	% of the net	% overlap*
Red	Psycho-neuro-endocrinology	53	39.0	50.9
Green	Neurocognitive sex/gender differences or functional brain differences sex/gender	46	33.8	41.3
Blue	Structural brain differences in sex/gender	20	14.7	50.0
Yellow	Cognitive neuroscience	17	12.5	38.9
Total		136	100	46.3

*Percentage of Nodes in the Network of *NeuroGenderings* Members

Table 2 summarizes these lines of research, as well as the number of words associated with each. Below we describe them in greater detail, noting the specific contributions made by the researchers who conform the *NeuroGenderings* movement.

Psycho-neuro-endocrinology

This line aggregates terms related to the endocrine system, the nervous system, psychology, and the critical perspective on neuroscience (red cluster, Figure 2B). The terms around "sex" confirm the link between hormones and human behavior and the relationship between the endocrine system, sex differences, and behavior. The terms connecting this line of research with the next one (neurocognitive sex/gender differences) evidence the discrepancy between the theory of sexual differences and the influence of non-hormonal factors surrounding sex.

The central part focuses on sexual orientation and behaviors, with terms referring to behavior and the social aspect of neuroscience. On the left, we find terms centered on intersexuality and sexual behavior. Finally, the bottom of this line of research is associated with critical views of sex differences, denoting the controversy over the political and social implications of neuroscience and its various perspectives. Serving as a bridge between this line of research and the next is the term "plasticity", which questions the immutability of the human brain.

This group is central to *NeuroGenderings* because it demonstrates the arbitrariness in establishing a dichotomy between men and women, as confirmed by the theory of sexual differences (red cluster, Figure 2C). Some terms fall outside the focus of *NeuroGenderings*, whereas others have a stronger presence, highlighting the social aspect of their neuroscientific work, for which they demand more attention. The number of terms on the left side, referring to sexual orientation and behaviors, is less than in the base map, indicating that *NeuroGenderings*' themes mark the connection between sensitivity and motor areas and between behavior, functionality, and similarities.

Neurocognitive sex/gender differences or functional brain differences sex/gender

In this second line of research, we find two central nodes that aggregate relationships with other terms, highlighting the interaction between the brain and behavior (green cluster, Figure 2B). Here, there are terms referring to differences in

brain organization between sexes. There are also terms related to brain functions and areas where differences between sexes have been found. In the same area, we detect terms related to the study of differences in brain regions and their organization, to debate whether there is bias in the studies, and their relationship with the social and political problems that a patriarchal reading of neuroscience on sex/gender entails.

The specific works of *NeuroGenderings* (green cluster, Figure 2C) focus on functions and anatomies that show sex differences. They do not deny the differences between brains, but rather question them from the exclusive categorization of a male brain and a female brain and their respective impact on human behavior. In the area of terms related to functions and areas of the brain where sex differences are reportedly found, terms that emphasize the differences between men and women are present on the outer edge of the cluster; this indicates the importance of neuroscientific determinism, which does not align with *NeuroGenderings*. The lower part is related to neuroscience and its socio-political aspects, demonstrating a concern with these issues.

Structural brain differences in sex/gender

The terms in this line of research (blue cluster, Figure 2B) include parts of the brain, as well as variables of special importance in the theory of sex differences, referring to the existence or absence of a male brain and a female brain. There are also terms reflecting the contrast between culture and experience as opposed to purely biological issues. This group of terms is paired with the lower part through the term "dimorphism," which highlights the notion of the existence of male and female brains solely from this anatomical perspective of brain activation by sex. For *NeuroGenderings* (blue cluster, Figure 2C), these anatomical or functional differences are not determinants in the exclusive classification of a "male" and "female" brain, nor do they correspond to a classification of abilities or behaviors according to gender. *NeuroGenderings* can review these variables to determine if the interpretation of results from neuroscientific experiments is biased.

Cognitive neuroscience

This is the line of research with the fewest terms (yellow cluster, Figure 2B). It includes terms related to cognitive task performance and is closely related to the previous two. Other terms in the cluster address the real-time bidirectionality between living brains and artificial components or machines.

This line of research is the least represented by *NeuroGenderings* (yellow cluster, Figure 2C). It contains terms related to the relationship that *NeuroGenderings* establishes between cognitive performance and training, rather than the relationship with purely hormonal, anatomical, and functional aspects, once again demonstrating their responsibility in the epistemological review of sex/gender differences or similarities.

4.2. Controversy identification

The reputational analysis (see Annex IV: *https://zenodo.org/doi/10.5281/zenodo.10141723*) conducted prior to the controversy analysis confirms the significance of social networks as an appropriate space to explore the social reception of the *NeuroGenderings* movement. This step is necessary to reinforce the relevance of using altmetrics in any study of this kind (**Robinson-García**; **Ràfols**; **Van-Leeuwen**, 2018).

The 56 works associated with the *NeuroGenderings* movement identified aggregate a total of 15,598 mentions according to *Altmetric.com*. Among them, *Twitter* gathers 13,448 mentions, the highest percentage (72.3%). Far behind lie the

Title	Journal	News	Blogs	Facebook	Wikipedia	Reddit
Neurosexism: the myth that men and women have different brains.	Nature	19	8	77	10	12
Dump the "dimorphism": Comprehensive synthesis of human brain studies reveals few male-female differences beyond size	Neurosci. Biobehav. Rev.	58	13	4	8	3
How hype and hyperbole distort the neuroscience of sex differences	PLoS Biology	1	0	0	1	3
The future of sex and gender in psychology: Five challenges to the gender binary.	American Psychologist	18	2	3	7	1
Far-Right Revisionism and the End of History | Alt/Histories		5	2	0	0	1
Sex, health, and athletes	BMJ	11	8	0	52	0
Out of Bounds? A Critique of the New Policies on Hyperandrogenism in Elite Female Athletes	Am. J. Bioeth	10	6	5	16	0
Recommendations for sex/gender neuroimaging research: key principles and implications for research design, analysis, and interpretation	Frontiers Human Neurosc.	19	6	10	13	0
Neurofeminism and feminist neurosciences: a critical review of contemporary brain research	Frontiers Human Neurosc.	1	1	9	13	0
Plasticity, plasticity, plasticity…and the rigid problem of sex	Trends Cogn. Sci.	12	4	3	13	0
Journal of neuroscience research policy on addressing sex as a biological variable: Comments, clarifications, and elaborations	J. Neurosci. Res.	1	0	1	13	0
On sex/gender related similarities and differences in fMRI language research	Brain Res. Rev.	0	2	0	6	0
His brain, her brain?	Science	4	5	8	5	0
NextGenVoices — Results	Science	0	2	4	2	0
Hardwired for Sexism? Approaches to Sex/Gender in Neuroscience	Neuroethics	5	2	0	2	0
Beyond sex differences: new approaches for thinking about variation in brain structure and function	Philos. Trans. R. Soc. B	12	5	3	1	0
Neuroethics, Gender and the Response to Difference	Neuroethics	0	4	0	1	0
Far-Right Revisionism and the End of History		6	0	0	0	0
		182	70	127	163	20

Figure 3. Top 10 works with the highest number of mentions for the five analyzed platforms

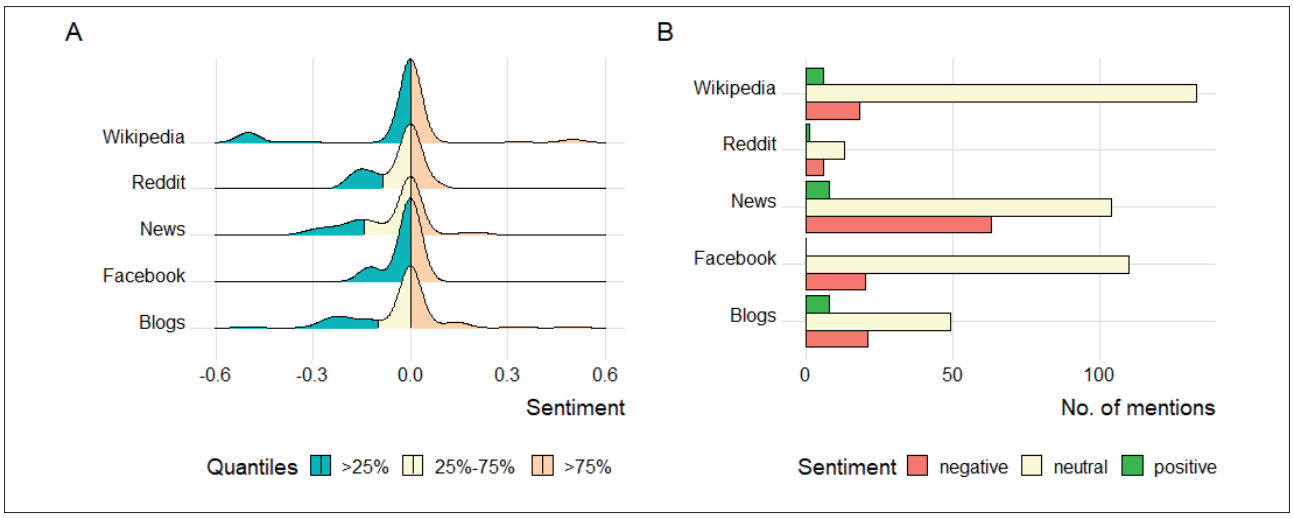


Figure 4. Sentiment analysis by altmetric source. A) Distribution of scores and B) Categorization of mentions according to the type of sentiment they evoke. 0 = Neutral or undetermined sentiment, < 0 = Negative sentiment, and > 0 = Positive sentiment. P-values are included for Fisher's test of proportions. The Fisher test for Counting data shows a value of $p < 0.001$ between social networks.

bibliographic manager *Mendeley*, with 4,492 mentions (24.2%), *Wikipedia* with 203 mentions, news with 198 mentions, *Facebook* with 137, 78 mentions in blogs, 20 discussions on *Reddit*, and the rest of the sources reporting fewer than 10 mentions.

Next, we focus on the five altmetric sources to be analyzed. They are mentions in news, blogs, *Facebook*, *Wikipedia*, and *Reddit*. Figure 3 shows the top 10 of the 19 works with the highest number of mentions for each of these sources. The altmetric source having the highest number of mentions is news (182), followed by *Wikipedia* (163), and *Facebook* (127). The other two sources accumulate fewer than 100 mentions altogether. The first noteworthy point is the strong concentration of mentions in the top two works. The first, *"Neurosexism: the myth that men and women have different brains,"* published in *Nature*, reviews the book *"The Gendered Brain,"* by Gina Rippon, a leading figure in the *NeuroGenderings* movement, denying differences in brain composition related to biological sex. The other work, titled *"Dump dimorphism: Comprehensive synthesis of human brain studies reveals few male-female differences beyond size,"* is published in the *journal Neuroscience & Biobehavioral Reviews*. This work points in the same direction; it is a meta-synthesis of the bibliography, providing empirical evidence of the lack of brain differences related to the biological sex of individuals.

Another noteworthy case is *"Sex, health, and athletes"* published in *the British Medical Journal*. This case stands out as it accumulates the highest number of mentions from *Wikipedia* (52). It pertains to a group of researchers also belonging to the *NeuroGenderings* movement, responding to the introduction of new hyperandrogenism policies by the *International Olympic Committee* that emerged after several athletes questioned the biological sex of South African runner Caster Semenya. The authors understand the committee's reaction, yet question the ethics and feasibility of the measures introduced.

Figure 4 displays the results of the sentiment analysis conducted by altmetric source. Most emotional values for all sources are around 0 (Figure 4A), showing the difficulty in extracting emotions from brief texts, as well as the impartial tone used in most of these sources. However, it also reveals that in cases where sentiment is expressed, it tends to be negative. To this regard, the notable cases are *Reddit*, news, and blogs, where 75% of the distribution lies in negative values. Another interesting case is *Wikipedia*. Although it mainly shows neutral messages, when it conveys negative sentiments, they tend to be quite polarized (≈ - 0.5).

This difference in the scale between positive and negative messages is evidenced when categorizing the mentions (Figure 4B). As observed, for all sources, there are significant differences between messages of a positive nature and those of a negative one, the number of positive mentions being much lower for all altmetric sources. This finding once again highlights the higher number of negative mentions origi-

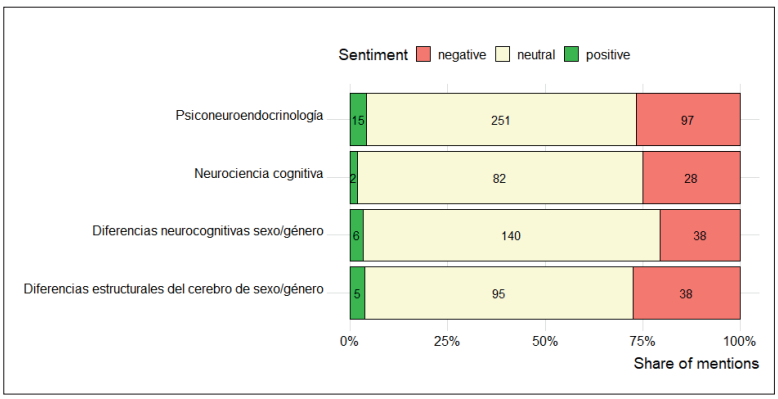


Figure 5. Proportion of mentions for each thematic cluster based on the type of emotions they evoke. The values in the graph indicate the raw number of mentions directed towards works belonging to the thematic cluster. The Fisher test for Counting data shows a value of $p = 0.63$ between subjects.

nating from news sources. Fisher's test confirms statistically significant differences in the proportion of positive, neutral or negative mentions per platform.

Finally, Figure 5 shows the sentiment analysis for each thematic block identified in Table 2. The block on Psychoneuroendocrinology gathers the highest number of mentions, followed by the block on neurocognitive differences related to gender/sex. Still, it is interesting to note how the proportion of positive messages is virtually non-existent, while the proportion of negative messages remains fairly constant for each theme (around 25% of mentions). Specifically, the neurocognitive differences block accumulates the lowest percentage of negative mentions. Indeed, when analyzing whether the difference in proportions varies thematically, we observe that this is not the case (p-value > 0.1). Table 3 presents some illustrative examples of negative mentions obtained for each identified line of investigation.

Table 3. Illustrative examples of negative mentions for each line of research identified.

Línea de investigación	Ejemplos de mención negativa
Psychoneuroendocrinology	*Stop using phony science to justify transphobia*
Neurocognitive Sex/Gender Differences or Functional Brain Differences Sex/Gender	*Sad about having a boy not a girl? Your distress might be real but 'gender disappointment' is no mental illness*
Structural Brain Differences in Sex/Gender	*Arguing over whether girls can't or won't study science stops us fixing the problem*
Cognitive Neuroscience	*NSW inquiry rejects expert advice on Parental Rights Bill, and it will cause students to suffer*

5. Discussion and conclusions

This work proposes a combination of bibliometric, altmetric, and natural language processing techniques to identify social controversies surrounding scientific issues. To achieve this, we selected a paradigmatic case study, that of the *NeuroGenderings* movement. It is a case surrounded by controversy, as it proposes the end of brain and cognitive differentiations attributed to the biological sex of individuals. Therefore, it represents a case study that is prone to controversy, impacting not only the scientific realm but also social discussions related to the feminist movement, the transgender movement, as well as recent controversies in the sports world, where the biological sex of certain athletes has been questioned (**North**, 2019). These implications makes it an ideal subject for testing the methodological proposal we present.

We began with a seminal set of works produced by different scientific exponents of the *NeuroGenderings* movement to identify the cognitive field upon which this movement is built. This was achieved by applying science mapping techniques based on citation and co-word networks. Four major lines of research could be identified, essentially vertebrating the scientific literature on the theory of brain sexual differentiation that the *NeuroGenderings* movement challenges. The detected lines of research are:

- Psychoneuroendocrinology.
- Neurocognitive differences related to gender/sex.
- Structural brain differences related to gender/sex.
- Cognitive neuroscience.

Psychoneuroendocrinology and structural brain differences are the lines with major contributions from *NeuroGenderings* (see Table 2).

For the analysis of social controversies, we used Altmetric.com to identify mentions in scientific literature from non-academic fields. Unlike other works likewise focused on the analysis of controversies in science (e.g. **Lamers** *et al.*, 2021), this research effort is characterized by focusing the object of analysis outside scientific discourse to understand the type of reception that science obtains in other social fields (**Torres-Salinas** *et al.*, 2023). We focused on five altmetric sources: news, blogs, *Wikipedia*, *Facebook*, and *Reddit*. The reason these sources were selected and not others is purely pragmatic, as they accumulate a sufficient number of mentions and include the full-text title of the mention. An important limitation is the exclusion of *X* (former *Twitter*) from our analysis; although it is one of the richest altmetric sources (**Robinson-García** *et al.*, 2014), its recent changes in API access policy kept us from accessing the full text of mentions.

The results obtained differ from other similar studies applying sentiment analysis to altmetric sources (**Friedrich** *et al.*, 2015; **Hassan** *et al.*, 2020). These studies also found a predominance of neutral messages, but there were more positive than negative messages. This may be traced to several reasons. Firstly, the source analyzed in those studies is Twitter, so that its nature may differ from the sources studied here. Secondly, these studies work with larger datasets and do not analyze particular case studies. Precisely the case studied here may be determinant for our results. Indeed, our case selection was deliberately intended to identify controversy, and our methodology appears to capture it.

As a future line of work, we propose extending this methodology to entire areas and fields of knowledge, to establish comparisons between topics and validate the results presented in this study., We can therefore confirm that analyzing scientific controversies in the social sphere is feasible when combining natural language processing techniques, traditional bibliometric techniques, and altmetrics. It will be interesting to test further, more advanced discourse analysis methodologies than sentiment analysis, and work with larger data corpora to explore hotspots in scientific debate on a

macro level. Such studies may significantly benefit from open sources like *Wikipedia* (**Arroyo-Machado** *et al.*, 2022) or open access works, allowing for the analysis of complete text mentions and scientific works to underline discrepancies and similarities in the emotional polarity detected in both the scientific and the social realm. In this sense, we consider that our methodological contribution has the potential to allow the creation of maps of social controversy in science as opposed to maps of scientific controversy.

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