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FUNCTIONAL NEURORADIOLOGY

Is advanced neuroimaging for neuroradiologists? A systematic review of the scientific literature of the last decade

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Abstract
Introduction To evaluate if advanced neuroimaging research is mainly conducted by imaging specialists, we investigated the number of first authorships by radiologists and non-radiologist scientists in articles published in the field of advanced neuroimaging in the past 10 years.
Methods Articles in the field of advanced neuroimaging identified in this retrospective bibliometric analysis were divided in four groups, depending on the imaging technique used. For all included studies, educational background of the first authors was recorded (based on available online curriculum vitae) and classified in subgroups, depending on their specialty. Finally, journal impact factors were recorded and comparatively assessed among subgroups as a metric of research quality.
Results A total number of 3831 articles were included in the study. Radiologists accounted as first authors for only 12.8 % of these publications, while 56.9 % of first authors were researchers without a medical degree. Mean impact factor (IF) of journals with non-MD researchers as first authors was significantly higher than the MD subgroup ($p < 10^{-20}$), while mean IF of journals with radiologists as first authors was significantly lower than articles authored by other MD specialists ($p < 10^{-11}$).
Conclusions The majority of the studies in the field of advanced neuroimaging in the last decade is conducted by professional figures other than radiologists, who account for less than the 13 % of the publications. Furthermore, the mean IF value of radiologists-authored articles was the lowest among all subgroups. These results, taken together, should question the radiology community about its future role in the development of advanced neuroimaging.

Keywords Systematic review · Advanced neuroimaging · Authorship · MRI

Introduction

In the last years, the development of a number of different advanced MRI techniques that allow for the study of a large number of anatomical and functional conditions of the human brain permitted for a rapid forward leap in the field of neuroimaging research [1].

Indeed, the volume of neuroimaging scientific literature has been continuously growing, with a large amount of papers published every year [2]. These researches find publication on an ever-increasing number of journals in both the radiology and non-radiology fields [2, 3]. For radiology researches, an increase in the number of authors per study during the time has been found [4], with a clear relationship between the number of authors and the impact factor of the journal in which the study is published [5].

The role and the contribution of imaging specialists in the authorship of radiology publications have been already addressed in the recent years. In particular, Sardanelli and colleagues [6] evaluated the inclusion of imaging specialists as authors of systematic reviews on diagnostic and interventional

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imaging researches and its relation with the quality of the research. Similarly, Ray and colleagues [7] investigated the number of radiologist and non-radiologists as first authors in researches in the field of interventional radiology.

To the best of our knowledge, a systematic review of the scientific literature of the advanced neuroimaging techniques researches to evaluate the contribution of radiology specialists has not been performed yet.

We therefore aimed to investigate the role of radiologists and non-radiologist scientists by assessing the number of first authorships in articles of advanced neuroimaging techniques published in the scientific literature during the past 10 years, to evaluate if neuroimaging researches are mainly conducted by imaging specialists.

Material and methods

The following study was a retrospective bibliometric analysis of the scientific literature in the field of advanced neuroimaging of the last 10 years (from January 1, 2006, to January 1, 2016), based on data publicly available on the National Library of Medicine MEDLINE database.

Articles in the field of advance neuroimaging were divided in four groups, based on the technique used in the study. These were, respectively, functional MRI (fMRI) and VBM studies (group 1), diffusion tensor imaging (DTI) articles (group 2), magnetic resonance spectroscopy (MRS) researches (group 3), and perfusion-weighted imaging (PWI) works (group 4). Only researches published in English, focusing on the study of the brain and defined as journal articles, were included in the study. Articles were identified using the research strings listed in Table 1.

Exclusion criteria were then applied, to exclude the following types of studies: case reports, animal model studies, reviews, meta-analyses, and methodological and ex vivo researches.

For all the included studies, the educational background of the first author was recorded, and two groups were identified: a medical group (MD, including specialists, resident, and undergraduate medical students) and a non-medical group (Non-MD, including all subjects with any other degree excluding the medical). Subsequently, all subjects were then divided in subgroups, which for the MD group were radiologists, neurologists, geriatricians, psychiatrists, undergraduate medical students, and others (which included all the researchers with a medical degree but without any of the abovementioned medical specialties). For non-MD researchers, subjects were divided in three subgroups, the first including psychologists and neuropsychologists, the second composed by researchers who achieved a scientific degree (such as engineering, mathematics, or physics), and the last subgroup including researchers with other degrees (i.e., biology, biotechnology, etc.).

The first author's educational background was recorded based on available online curriculum vitae. When not available, these information were retrieved by business- or research-oriented social networking services (i.e., LinkedIn, ResearchGate, etc.). Researchers with uncertain or unavailable educational background were not included in the statistical analysis.

For the MD group, residents were considered as specialist and included in the respective group, depending on the residency program.

For papers with shared first authorship, only the first author's educational background was identified and included in statistical analysis.

Researches in which the first author proved to have two different educational backgrounds (i.e., radiologists and neurologists) at the time of publication were included as two different articles in the analysis.

In order to investigate the role of radiologist and non-radiologist scientists when researches were conducted on patient-based population, a second analysis was carried out, recording only researches that included subjects affected by a

Table 1 Research strings used for the inclusion of the articles in the present study

Research string	
(((((“magnetic resonance imaging”[MeSH Major Topic]) AND “brain”[MeSH Major Topic]) AND (“2006/01/01”[Date - Publication] : “2016/01/01”[Date - Publication])) AND “english”[Language])) AND ((“fmri”[Title/Abstract]) OR “voxel based morphometry”[Title/Abstract])	Group 1
(((((“magnetic resonance imaging”[MeSH Major Topic]) AND “brain”[MeSH Major Topic]) AND (“2006/01/01”[Date - Publication] : “2016/01/01”[Date - Publication])) AND “english”[Language])) AND ((“dti”[Title/Abstract]) OR “tractography”[Title/Abstract])	Group 2
(((((“magnetic resonance imaging”[MeSH Major Topic]) AND “brain”[MeSH Major Topic]) AND (“2006/01/01”[Date - Publication] : “2016/01/01”[Date - Publication])) AND “english”[Language])) AND “spectroscopy”[Title/Abstract]	Group 3
(((((“magnetic resonance imaging”[MeSH Major Topic]) AND “brain”[MeSH Major Topic]) AND (“2006/01/01”[Date - Publication] : “2016/01/01”[Date - Publication])) AND “english”[Language])) AND “perfusion”[Title/Abstract]	Group 4

disease, as defined in the current ICD of the World Health Organization [8].

Finally, for all works, journal impact factors at the year of publication of the article were obtained through the Thomson Reuters website [9], as a metric of research quality, and mean impact factor (IF) value was obtained for each group of researchers.

For the statistical analyses, different tests were applied. In particular, to test if any significant trend occurred between the categories in the different subgroups, a Cochran-Armitage trend test was applied. Possible differences between subgroups in term of IF were tested by a Mann-Whitney test, while its correlation with the subgroups was tested by using the Spearman's rank correlation coefficient.

Results

A total number of 7378 articles in the field of advanced neuroimaging were identified. Among these, 3563 researches matched the exclusion criteria and were, therefore, excluded from the subsequent analysis. For the remaining 3815 articles, the first author's educational background was identified for all studies except for 80 that were therefore excluded from the analysis, leaving a number of 3735 available articles. Additionally, in 96 papers, the first author proved to have two different educational backgrounds, leading to a final number of 3831 articles included in this study.

Among these 3831 articles, 2857 were included in group 1559 belonged to group 2177 were included in group 3 while the remaining 238 were added to group 4. The results of the analysis for all articles are listed in Table 2.

In particular, we found that radiologists signed as first authors only the 12.8 % of advanced neuroimaging publications, while 56.9 % of first authors were identified as non-MD researchers. When analyzing the percentage variation of MD researchers across different subgroups, we found an upward trend going from group 1 to group 4 (36.1 to 70.2 %, $p < 10^{-14}$) (Fig. 1).

When taking into account for the presence of patients in the study, 2038 articles were identified from the abovementioned 3831 hits and were divided as follows: 1314 articles in group 1, 429 in group 2, 144 in group 3, and the remaining 151 in group 4. Results of the analysis for the articles with the inclusion of patients are listed in Table 3.

When considering only studies dealing with patients, radiologists were identified as first authors in 17.8 % of the cases, with a percentage of non-MD researchers of 43.0 %. Similar to what was found for all articles, there was a significant upward trend of MD researchers going from group 1 to group 4 ($p < 10^{-14}$) when considering only studies conducted with the inclusion of patients.

Among the first authors of the MD group, the percentage of radiologists showed no significant variation based on the inclusion or not of patients in the studies (30.1 vs 29.7 %, $p = 0.88$), with the number of radiologists significantly increasing from group 1 to group 4 (specifically, from 19.9 to 59.9 %, $p < 10^{-14}$) (Fig. 2), even when considering only studies dealing with patients ($p < 10^{-14}$).

We then analyzed the IF of the journal in which the articles were published, with the results being shown in Table 4.

In particular, we found that the mean IF relative to non-MD first authors was significantly higher than the one of the MD subgroup (4.400 ± 2.53 vs 3.826 ± 2.27, $p < 10^{-20}$), with statistically significant negative correlation between IF and subgroups from group 1 to group 4 (from 4.261 ± 2.50 to 3.883 ± 1.94, $\rho = -0.098$, $p < 10^{-8}$) (Fig. 3). This last correlation remained significant even when considering only studies with the inclusion of patients (from 4.075 ± 2.70 to 3.734 ± 1.91, $\rho = -0.100$, $p < 0.0001$). Finally, among the MD group, the IF of articles with radiologists as first authors were always significantly lower than the articles authored by any other MD specialists (3.245 ± 1.95 vs 4.068 ± 2.36, $p < 10^{-11}$), with a difference that remained significant even when considering only studies dealing with patients ($p < 10^{-9}$), which is similar to what was described above for the contrast of MD vs non-MD.

Discussion

Magnetic resonance is a powerful tool for the study of the central nervous system, allowing to investigate different aspects of brain anatomy, physiology, and physiopathology. Modern neuroscience makes use of a large variety of sophisticated techniques and software for scientific purposes that often requires a multidisciplinary approach with the involvement of many different professional expertise. All this has contributed to the growing popularity of advanced MRI techniques among researchers [10]. We wanted to dig deeper into the role played by MD scientists, especially radiologists, in neuroimaging research, analyzing the articles published in this field of advanced neuroimaging in the last decade.

The main result emerging from our study is that the first author of the 56.9 % of advanced neuroimaging scientific literature is a researcher without a medical degree. This percentage rises up to 72.7 % in studies conducted only on healthy subjects, while it drops to 43.0 % in case of studies concerning subjects affected by pathological conditions. Despite the expected rise of percentage when considering only the studies conducted on healthy controls, which were presumably conducted to explore physiological mechanisms in the healthy brain, it should be noted that more than 40 % of the articles with the inclusion of patients are firstly signed by non-MD researchers.

Table 2 Percentages of first authorships in articles in the field of advanced neuroimaging

	Radiologist	Neurologist	Geriatricians	Psychiatrist	MD student	Other (MD)	Psychologist	Non-MD scientific degree	Other (non-MD)
All studies	492	423	6	370	23	337	1225	612	343
	12.8 %	11.0 %	0.1 %	9.7 %	0.6 %	8.8 %	32.0 %	16.0 %	9.0 %
Group 1	205	301	4	290	15	215	1125	424	278
	7.2 %	10.5 %	0.1 %	10.2 %	0.5 %	7.5 %	39.4 %	14.8 %	9.7 %
Group 2	132	79	0	57	2	64	74	115	36
	23.6 %	14.1 %	0.0 %	10.2 %	0.4 %	11.5 %	13.2 %	20.6 %	6.4 %
Group 3	55	16	0	15	2	32	13	27	17
	31.1 %	9.0 %	0.0 %	8.5 %	1.1 %	18.1 %	7.3 %	15.2 %	9.6 %
Group 4	100	27	2	8	4	26	13	46	12
	42.0 %	11.3 %	0.8 %	3.4 %	1.7 %	10.9 %	5.5 %	19.3 %	5.0 %

Group 1: functional MRI- and voxel-based morphometry articles; group 2: diffusion tensor imaging articles; group 3: magnetic resonance spectroscopy articles; group 4: perfusion-weighted imaging articles

Stratifying this results into the four MR subgroups, the distribution of first authorship showed a significant increase in the proportion of MD researchers from group 1 to group 4. Furthermore, we proved that this trend is, at least in part, independent from the inclusion of healthy controls (HCs) or patients in the studies. More specifically, when we investigated the role of radiologists in the field of neuroimaging research comparing to other MD specialists, we found a similar upward trend of significance across the four subgroups, likewise independent from the inclusion of patients. A possible explanation for this result is that techniques measuring neuronal activation and cerebral tissue connectivity, like fMRI and DTI, allow for the investigation, in a broad sense, of the physiological and pathophysiological bases of cerebral functions, either in a normal or in a pathological state [11, 12]. These techniques have tremendously contributed to the understanding of brain physiology in healthy subjects, a population easily accessible also to non-MD neuroscientists, who developed a robust "know-how" of these analysis techniques over the years. Moreover, it can be easily seen the attractiveness for the clinicians, who often run imaging facilities, of these techniques, which allow to reliably assess processes going on in the brain of their patients, instead of extrapolating them using indirect methods. Thus, it is easy to understand how these techniques may be more attractive for non-MD neuroscientists or MD specialists other than radiologists.

On the other hand, when considering techniques investigating biochemical changes or variation in blood perfusion (such as MRS and PWI) of cerebral tissue, the percentage of medical doctors involved as first authors proved to be higher. Similar to what discussed before, a possible explanation probably lies

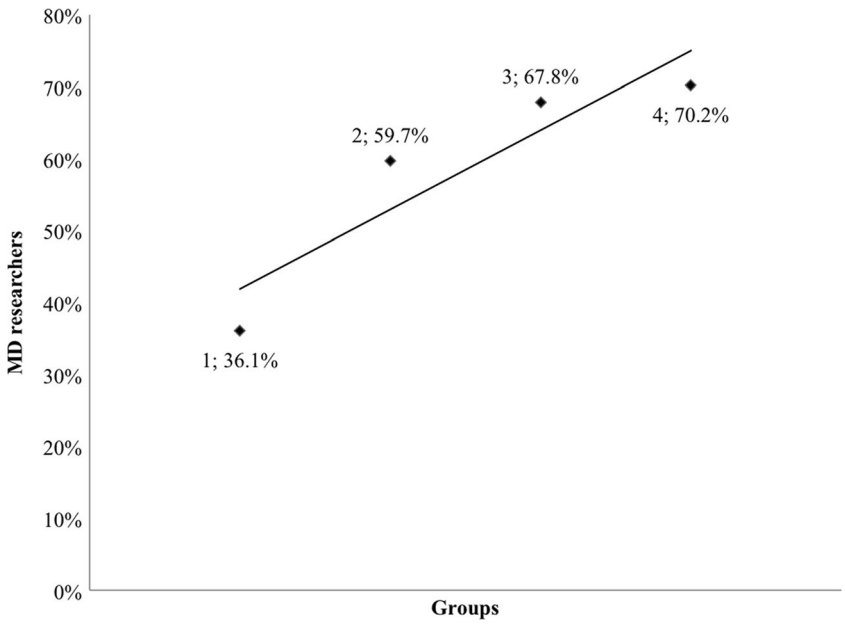

Fig. 1 Graphic shows the percentage of MD researchers depending on the subgroup, with an upward trend going from group 1 to group 4 ($p < 10^{-14}$). Group 1: functional MRI- and voxel-based morphometry articles; group 2: diffusion tensor imaging articles; group 3: magnetic resonance spectroscopy articles; group 4: perfusion-weighted imaging articles

Table 3 Percentages of first authorships in articles in the field of advanced neuroimaging, with the inclusion of patients in the study

	Radiologist	Neurologist	Geriatricians	Psychiatrist	MD student	Other (MD)	Psychologist	Non-MD scientific degree	Other (non-MD)
All studies	345	310	2	262	17	226	445	276	155
	17.8 %	16.0 %	0.1 %	13.5 %	0.9 %	11.6 %	22.9 %	14.2 %	8.0 %
Group 1	126	207	1	198	12	127	373	158	112
	9.6 %	15.8 %	0.1 %	15.0 %	0.9 %	9.6 %	28.4 %	12.0 %	8.5 %
Group 2	101	64	0	48	2	54	57	79	24
	23.5 %	14.9 %	0.0 %	11.2 %	0.5 %	12.6 %	13.3 %	18.4 %	5.6 %
Group 3	48	14	0	11	2	31	8	15	15
	33.3 %	9.7 %	0.0 %	7.6 %	1.4 %	21.5 %	5.6 %	10.4 %	10.4 %
Group 4	70	25	1	5	1	14	7	24	4
	46.4 %	16.6 %	0.7 %	3.3 %	0.7 %	9.3 %	4.6 %	15.9 %	2.6 %

Group 1: functional MRI- and voxel-based morphometry articles; group 2: diffusion tensor imaging articles; group 3: magnetic resonance spectroscopy articles; group 4: perfusion-weighted imaging articles

in the application, both in clinical and scientific researches, of these two techniques. Indeed, it is known that both MRS and PWI emerged as more clinical techniques with a major impact on diagnostic evaluation, therefore belonging firstly to MD [13–15] and, in particular, to radiologists.

We then moved to analyze the IF of the journal in which the articles were published, as an indirect measure of research quality [16, 17]. Our first result was that the IF of the non-MD group was significantly higher than the one of the MD subgroup. It should be noted that, when taking into account for the presence of patients in the articles, IF were significantly lower compared to studies conducted solely on HCs. Moreover, a negative correlation between IF and MR subgroups was found both for the entire group or when considering only those with patients. Furthermore, the IF of articles with radiologist as first authors compared to those authored by other MD specialties resulted to be constantly lower when compared to all the other subgroups, which were independent from any possible stratification (e.g., the inclusion of patients in the articles or the subdivision based on the technique). These results may lead to an ambiguous interpretation of the low impact of the MD's (and in particular of the radiologists') researches on the scientific community. Actually, as discussed before, our results could be partly explained by the fact that non-MD researchers and, to a lesser extent, MD other than radiologists are more involved in researches in the field of brain pathophysiology. Therefore, the results of their work tend to find place on neuroscience journals addressed to a larger and multidisciplinary audience. Conversely, the radiologists' researches usually find place on category journals with a more selective and/or productive audience and, consequently, a lower IF.

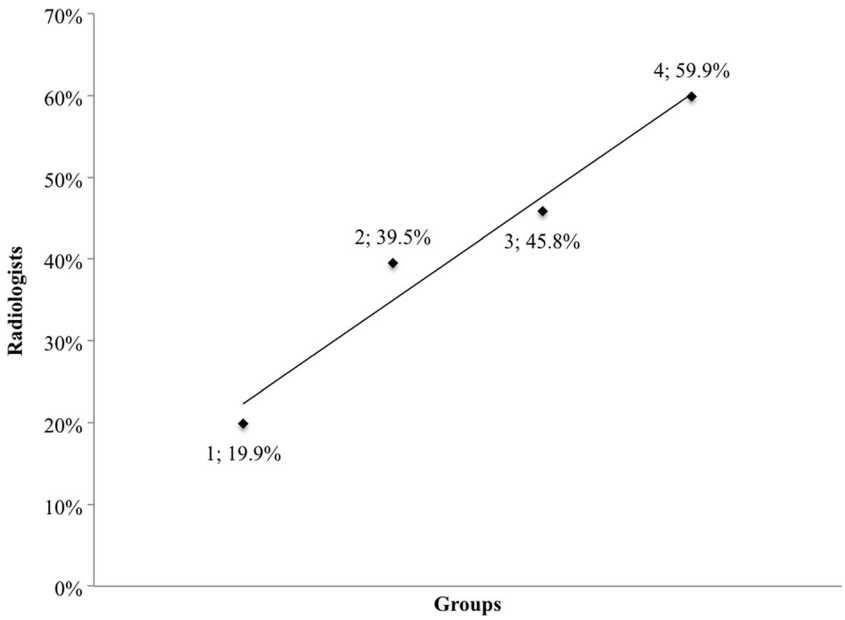

Fig. 2 Graphic shows the percentage of radiologists, among all MD researchers, depending on the subgroup, with an upward trend going from group 1 to group 4 ($p < 10^{-14}$). Group 1: functional MRI- and voxel-based morphometry articles; group 2: diffusion tensor imaging articles; group 3: magnetic resonance spectroscopy articles; group 4: perfusion-weighted imaging articles

Table 4 Mean impact factor of articles in the field of advanced neuroimaging included in the study

	Radiologist	Neurologist	Geriatricians	Psychiatrist	MD student	Other (MD)	Psychologist	Non-MD scientific degree	Other (non-MD)
All studies	3.355	4.230	5.859	4.355	4.152	3.771	4.646	4.128	4.288
	±1.91	±2.00	±3.08	±2.64	±3.14	±2.21	±2.68	±2.29	±2.16
Group 1	3.523	4.304	4.793	4.163	4.417	3.938	4.648	4.174	4.326
	±2.28	±1.98	±2.11	±2.41	±3.66	±2.30	±2.74	±2.42	±1.99
Group 2	3.157	4.157	n.a.	5.116	4.892	3.436	4.683	4.020	3.687
	±1.47	±2.17		±3.14	±2.07	±1.92	±1.70	±1.86	±2.07
Group 3	2.889	3.069	n.a.	5.366	2.471	3.063	4.139	4.157	4.98
	±1.52	±1.23		±4.24	±0.17	±2.33	±1.97	±2.60	±4.18
Group 4	3.493	4.225	7.992	4.098	3.541	4.24	4.825	3.952	4.255
	±1.73	±1.95	±4.53	±2.52	±2.26	±1.79	±2.17	±1.84	±1.86

Group 1: functional MRI- and voxel-based morphometry articles; group 2: diffusion tensor imaging articles; group 3: magnetic resonance spectroscopy articles; group 4: perfusion-weighted imaging articles. IF values are mean ± standard deviation

n.a. not applicable

It could be therefore hypothesized that the radiological scientific community has not expanded enough, in the advanced neuroimaging field, in response to the increasing interest by non-radiologist researchers in the last years (for the reasons discussed above). However, this speculation remains to be proven, and future studies, focusing on the modifications during the time in the authorship of papers in the field of neuroimaging, should be performed.

Different from previous works that identified the professional background of authors based on the academic affiliation [6], we identified for each researcher his/her curriculum vitae. This approach was chosen in order to avoid possible errors in the assignment of the subgroup, due to the possibility of an author being affiliated to a multidisciplinary department, having two or more affiliations, or being affiliated to a department (e.g., neurology) but actually having a different professional background (e.g., psychology). Furthermore, we decided to minimize false positive by excluding from the analysis those authors in which an information about the educational background was not available or unclear.

We chose to exclude case reports from our analysis, since their inclusion may have induced a significant selection bias, as they are mainly authored by radiologists, being primarily involved in the description of the diagnostic features of single subjects.

Finally, in our analysis, we decided to consider as two different articles those researches that proved to have two different educational backgrounds (i.e., radiologists and

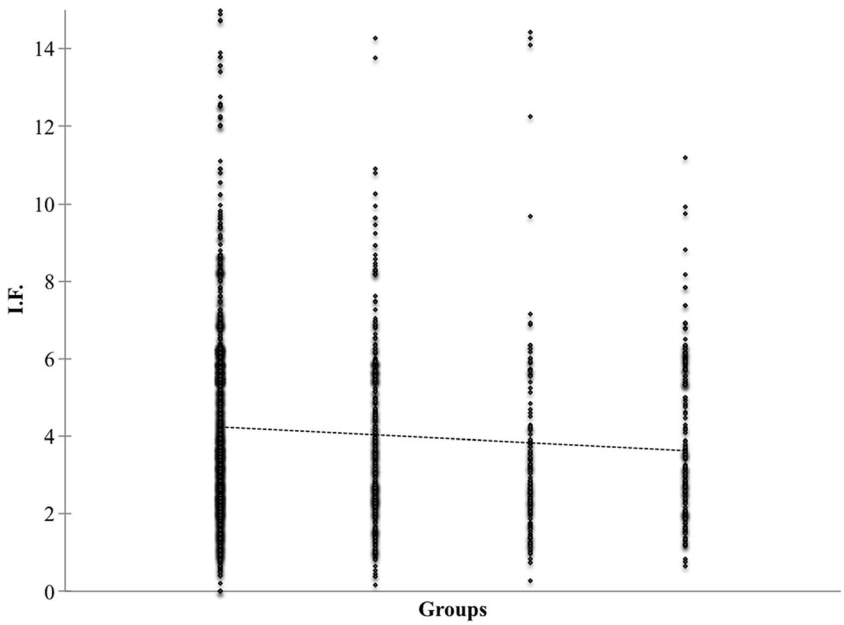

Fig. 3 Graphic shows the distributions of IF across different subgroups ($\rho = -0.098$, $p < 10^{-8}$)

neurologists) at the time of publication. The rationale behind this choice was to exclude possible bias in the aleatory inclusion of a researcher in a group rather than in another.

Some limitations of our work should be considered. We are aware that authorship always refers to a list of participants who gave a contribution to experimental results and/or data interpretation [18]. Indeed, each article is signed by many different professional figures with variable proportion from one study to another, each contributing to the intellectual contents of the work. Nevertheless, we decided to consider only the first author in our analysis, because he is generally the study designer and the one who plans and defines the final structure of the research work.

Also, the processing tool used in any single paper was not analyzed in our study. It may be hypothesized that radiologists mainly used DICOM data and worked with OEM software tools, which were readily available on the scanners or on the diagnostic consoles, while non-radiologists and non-MD researchers mainly performed group analyses using software not for diagnostic purposes (processing NIfTI data, e.g., SPM, FSL, FreeSurfer, etc.). However, it should be considered that the large number of these software packages is likely to preclude an automated classification of the manuscripts from this standpoint. Even more, the even larger number of in-house software tools (running on many different environments, such as MATLAB, IDL, and C++), used by neuroscientists for their voxel- or ROI-based analyses, would have inevitably led to an underestimation of the studies processed using non-clinical software. Accordingly, further dedicated studies are needed to clarify this issue.

Finally, we decided to evaluate only studies published in English-speaking scientific journals that were present in a well-known scientific database (MEDLINE) within a definite time interval and therefore have missed some relevant articles that did not matched our inclusion criteria. However, we believe that the high number of the articles that we analyzed, and the inclusion of the most widely diffused scientific journals in the field, makes the impact of these possible missed hits least important, and the highly significant differences that we observed cannot be affected.

In conclusion, we proved that the majority of the studies in the field of advanced neuroimaging in the last decade is conducted by professional figures other than radiologists, who account for less than 13 % of the publications. Furthermore, the mean IF value of these articles fared lowest between all subgroups. These results, taken together, should question the radiology community about its role in the future of advanced neuroimaging.

Compliance with ethical standards We declare that this manuscript does not contain clinical studies or patient data.

Conflict of interest We declare that we have no conflict of interest.

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