

Laterality and education: A bibliometric study based on high-impact search engines

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Abstract:

In recent years, the volume of research on laterality has considerably increased. However, there is a gap in understanding its relationship with education because no comprehensive studies have synthesized all existing information on this topic. Therefore, this study aims to conduct a bibliometric analysis of scientific and academic publications from the past decade (2012–2022) on laterality and education. This study uses high-impact search engines, specifically Web of Science, to compile and analyze relevant works in this field. This research employed an ex post facto retrospective design. The study used a subscription-based database provided by the University of Alicante, specifically the Web of Science Core Collection. This database encompasses various fields, including Sciences, Social Sciences, and Arts and Humanities, and includes 254 categories such as Education Research, Pedagogy, Science Disciplines, and Special Education. After applying the search strategy and various filters in the database, the data were screened according to established inclusion and exclusion criteria. The final sample comprised N = 281 documents. Analysis of these results highlights the benefits of laterality for enhancing motor, neuromotor, and psychomotor skills, which are crucial for the holistic development of individuals. Because these aspects align with key educational objectives, it is recommended to implement classroom methodologies that promote laterality-related activities to assess their effectiveness in practice.

Key Words: laterality, education, motricity, psychomotricity, neuromotricity

Introduction

The human species is characterized by an apparent physical symmetry. However, this and other species are truly asymmetrical at the structural and functional level. Humans have a genetic tendency towards asymmetry and lateralization of the diverse functions of the brain, where one hemisphere predominates over the other in the performance of certain actions, despite the fact that for proper functioning both should complement each other. This asymmetry is reflected in the greater use of one side of the body over the other and, therefore, in greater dexterity for different activities. Nevertheless, the proper functioning of these connections depends on the developmental process of the individual.

Research interest in the study of laterality arises from the need to explain the observation of an increased lateral manual, pedal, visual and auditory dominance in all cultures. Over the years, numerous social, historical and religious debates have emerged about the implications of laterality in a variety of fields of interest.

Today, a large number of publications on the study of laterality can be found. However, there is a research niche in terms of its connection with the educational field since no studies have been found that parcel up all the available information regarding laterality and education. It is for this reason that was considered of interest to carry out a bibliometric study of these characteristics.

In recent years, studies have been conducted on this topic, including Ferrero et al. (2017) and Ocklenburg et al. (2020). The first is a systematic review and meta-analysis of the studies published since 1900 that relate cross-laterality and academic achievement and intelligence. The second paper discusses trends likely to shape laterality research at a general level in the 2020s.

The most recent studies affirm that early stimulation during the first stages of human evolution facilitates motor and cognitive maturation. Since motor action is present in our daily lives, it is important that it is also present in the educational environment. According to Rigal (2006), psychomotor development also influences the acquisition of knowledge since it is through motor action that we obtain information on our surroundings, an essential element in the formation of thinking. More specifically, neuropsychology considers that laterality exerts a strong influence not only on developmental processes but also on learning and, therefore, on the prevention of potential difficulties (Borrillo et al., 2015).

This article covers the research on laterality and education in general on the one hand and laterality and music on the other hand, where dance has also been included. For this purpose, and due to the large amount of existing published material on laterality, the search has been carried out in one of the most relevant primary

search engines: Web of Science. Furthermore, in order to provide information about the most current findings, the results have been limited to the last ten years, from 2012 to 2022.

Laterality

Laterality is defined as the functional predominance of one side of the body over the other, which is determined by the supremacy of one of the cerebral hemispheres, because despite the similarity of both sides in appearance and structure, they are not biologically identical and have different abilities in terms of information processing (Hellige, 2002). Laterality is approached from three points of view: motricity, psychomotricity and neuromotricity. In the first place, motricity refers to an individual's ability to perform movements and control his or her body. It involves the control of muscles through the central nervous system, coordination, balance, locomotion and the ability to plan and execute motor actions.

In the second place, psychomotricity is understood, on the one hand, as the science that studies the relationship between the psychic and the motor and, on the other hand, as the technique to achieve different motor goals (Pastor, 2002). Psychomotricity develops three elements: motor competence, cognitive capacity and socioaffective intelligence (Andreu-Cabrera & Romero-Naranjo, 2021; Arnau-Mollá & Romero-Naranjo, 2022a, 2022b, 2024a, 2024b; Arnau-Mollá et al., 2024; Romero-Naranjo, 2012; 2020, 2022, 2023a, 2023b, 2023c, 2024; Mas-Mas et al., 2023; Penalva et al., 2023; Romero-Naranjo & Sayago-Martínez, 2021a, 2021b; Romero-Naranjo, Andreu-Cabrera et al., 2023; Romero-Naranjo, Pujalte et al., 2023; Romero-Naranjo, Sayago-Martínez et al., 2023; Suárez et al., 2024).

This concept was initially developed in Germany in the mid-19th century. However, several authors state that there is no consensus on the birth of psychomotricity at a specific date or in relation to specific authors (Andreu-Cabrera & Romero-Naranjo, 2021; Berrueto & Adelantado, 2006).

Da Fonseca (1998) argues that during the 19th century in the field of neurology, the body was studied in terms of understanding the functioning of the brain and its neural structures. From the psychoanalytic model, Freud (1920) explained human development from the perspective of movement and social interaction through motricity.

In the field of science and developmental psychology, Wallon (1925), who developed the first methods of psychomotor education, and later his pupil De Ajuriaguerra (1960), who consolidated the foundations of psychomotricity, stand out. According to both authors, psychomotricity facilitates human development and, at the same time, is the product of the interaction between internal factors, at the biological level, and external factors, at the cultural level. They also state that, from the educational, therapeutic and rehabilitation spheres, through an environment full of stimuli, the maturation of the nervous system can be favoured (Andreu-Cabrera & Romero-Naranjo, 2021). However, it was the French Jean Le Boulch (1966) who established the relationship with the educational field following the studies of Wallon and De Ajuriaguerra.

In 1967, the French Society for Psychomotor Education and Re-education was founded, which included personalities such as André Lapierre, Pierre Vayer and Bernard Acouturier, who supported a methodology based on corrective gymnastics with exercises for the muscles.

Later, Piaget (1969) linked motor skills to intelligence regarding the development of cognitive functions, an issue that would be studied extensively later in relation to school performance and attentional and learning problems and, therefore, academic failure.

As a result, it can be seen how motor psychology shifts the focus of interest from motor execution to cognitive processes. Alongside the German and French schools, the Portuguese school also stands out, with its greatest representative, Vítor da Fonseca, professor at the Faculty of Human Motor Skills in Lisbon and pioneer in the systematic observation of psychomotor skills. Da Fonseca proposed the use of psychomotor skills as a tool for education and re-education in cases of children with special needs (Da Fonseca, 1998).

Given the diversity of schools that study psychomotor skills, debates arise around different concepts and conceptions of the motor and neurological development of infants and the relationship established between the two. As a result, very different models have emerged based on studies where different subject profiles are analysed. These schools have continued to study this area to this day and continue to make relevant contributions to it. Psychomotricity, as well as laterality, is of great importance in the development of the body schema and motor skills. For this reason, they are an important part of the work carried out in the early stages of education, more specifically in infant education. In this stage, the focus is on the integral development that enhances the physical, emotional, social and cognitive dimensions of children through the development of the physical skills (Mérida-Serrano et al., 2018). Pastor (2002) goes further and states that psychomotricity can be understood in the educational field as a methodology characterized by the use of body activity to develop different aspects of personality.

Motor and limb work regarding lateral dominance is especially evident in the subjects of Physical Education and Music, but not only in the first stages, but throughout all of them. However, there is a clear difference between the two subjects. In the former, there are patterns for the development of these skills, which is lacking in the latter. In other words, there is no systematization, since the most current methods of music education (Orff-Schulwerk, Dalcroze, Martenot, Kodály or Willems, among others) do not involve the development of the body schema in music, but have focused on the learning of music reading.

It is in this context that the BAPNE method was created, which is based on the work of psychomotor skills through musical motor activities using body percussion conceived as "rhythmic psychomotricity" (Romero-Naranjo, 2004). Laterality is addressed from the point of view of motricity, psychomotricity and, above all, neuromotricity. To this end, the use of language is introduced through activities that promote the double task.

This new understanding of motor development linked to neurology and the psyche was first widely defended by De Ajuriaguerra (1947). Nowadays, this new perception is characterized by the fact that it takes place within the framework of two concepts: that of neuromotor and that of psychomotor (Hernando & Useros, 2007). Hence, neuromotricity is conceived from two perspectives: as a discipline and as a methodology (Andreu-Cabrera & Romero-Naranjo, 2021). Therefore, on the one hand, it is understood as the part of neuroscience that studies the relationship between the nervous system and human motricity by analyzing the neurophysiological processes involved in the planning, control and execution of body movements. For this reason, it covers diverse areas of research. These include neuroscience, physiology, biomechanics, psychology and rehabilitation.

On the other hand, as a method, it is based on the idea that active movement and bodily experience enhance the formation of neural connections and consequently promote brain plasticity. The integration of movement and learning seeks to improve cognitive functions such as memory and attention to improve the cognitive development and academic performance of the students.

Types of laterality

When referring to laterality, we mean the motor dominance of one side of the body over the other. According to this, we find four types (Rigal, 1988): right, left, ambidextrous or undefined, and cross laterality.

Right and left laterality comprise the right or left sensory body segments respectively of eye, ear, hand and leg that are most used by the individual. In the case of right laterality, the left hemisphere is predominant in the brain, and in left laterality, the right cerebral hemisphere is the one that acts as a guide while the opposite part of the body performs the motor action.

Ambidexterity refers to the possibility of carrying out any motor action with both sides of the body and undefined laterality relates to the lack of a defined body lateral preference, that is, when there is not a clear and stable pattern. Finally, cross laterality applies when the dominant indices are not on the same side of the body. These crossovers can occur in any of the four items: eye, foot, hand and ear.

Lateral dominance

According to lateral dominance, there are four different types (Da Fonseca, 2000; Martín, 2015; Pellicer, 2013): visual, manual, pedal and auditory.

Visual dominance refers to the preference for the use of the more dominant eye in activities of daily life such as looking through a telescope or an orifice. Manual dominance relates to the preference for the use of the right hand or the left hand in the execution of motor actions such as eating, combing one's hair, or brushing one's teeth. Pedal dominance is the preference for the use of the right or left foot in activities involving, for example, precision or speed. Auditory dominance concerns the more frequent use of the right or left ear to receive auditory stimuli in response to sounds that require greater attention, such as a phone call or a crying baby.

All of the above leads us to the conclusion that the importance of a well-defined laterality is a reflection of the brain being well organized at a functional level. This results in the acquisition of clear body referents, the improvement of spatial orientation, the mastery of the body schema and a better integration of information and coordinated motor responses.

Method

This section presents the process of selecting the sample of articles that have been analyzed in this study.

Sample

This paper is a bibliometric review on laterality and the field of education based on Page et al. (2021) and Klerings et al. (2023). It was carried out using an ex post facto retrospective design (Montero & León, 2005). This is the reason why the procedure used was based on the search and selection of the documents on the topic followed by their classification according to their descriptors and the analysis of the data provided (Rosa et al., 1996). A total of 281 documents published between 2012 and 2022 have been selected from the academic search engine Web of Science. Although the Scopus search engine has also been consulted, the use of Scopus was discarded for two reasons. In the first place, it is a scientific search engine, so the field of education is not explicitly included, although it does include some publications on education. In the second place, there was a larger list of results in Web of Science and space constraints.

Tools

The data collection instrument has therefore been the Web of Science search engine, owned by the company Clarivate Analytics. This is a collection of databases of bibliographic references and citations that brings together publications from 1900 to the present day. The main one is the Core Collection, which covers the fields of Science, Social Sciences and Arts and Humanities. It has a total of 254 categories, including Education and Educational Research, Education, Scientific Disciplines and Special Education.

Access to the database has been obtained through the subscription of the University of Alicante.

Procedure and analysis

The main objective of the search strategy was to obtain as many results as possible related to our object of study, laterality in relation to education. To this end, three strategies were designed. The first of these related laterality, education and music; the second linked laterality and music; and finally, a strategy that connected laterality and dance, since we consider that music encompasses both, that is, laterality from movement and expression through the use of music. We have chosen to design these strategies in English as it is a search engine with a wide international scope. Furthermore, the Boolean operators of Web of Science, more specifically AND and OR, have been used. The keywords used are "laterality", "education", "music" and "dance". However, other related words have been added on top of these, which we will explain below. In the same way, all the terms entered have been written between quotation marks in order to narrow down the search and to clarify the cases of terms that consisted of two words. In addition, an asterisk (*) has been used at the end of some terms to ensure that the search engine would also include the results of all the words derived from the one selected.

Regarding the terminological variants used for each of the four central concepts presented above, firstly, for the term "laterality", it has been decided to add as many synonyms as possible. For this reason, the addition of the different types of laterality (e.g. "ambidexterity" or "cross* laterality") as well as the types of lateral dominance have been determined using both word combinations ("hand preference" or "hand dominance") and single words ("handedness").

Secondly, regarding the term "education", several combinations have been tested with words referring to the various educational stages, the students, and the institutions of both musical and non-musical careers.

Thirdly, since music and dance are related, we have chosen to introduce, in addition to "music" and "danc*", specific instruments in which laterality is involved, as well as terms referring to the different families of instruments and the musicians who play them. At first, the search strategy included terms related to movement, more specifically "movement" and "physical activity", but it was decided to eliminate this element because, on the one hand, the concept of laterality already implies movement by itself and, on the other hand, we realized that its use restricted the results. Therefore, with the use and combination of all these words, we obtained a fairly extensive search strategy which we decided to divide into several lines in order to organize and prioritize the areas to which laterality was related. In this way, it was decided to search for concepts referring to laterality in the title and those referring to music, dance and education in the theme.

The first strategy, which included laterality, education and music was the following: [Title] "laterality" or ("handedness" or "ambidexterity" or "cross* laterality" or "cross* dominance" or "hand dominance" or "leg dominance" or "eye dominance" or "ear dominance" or "manual preference" or "leg preference" or "eye preference" or "ear preference" or "footedness" or "eyedness" or "earedness" or "lateral preferenc*") and [Topic] ("music" or "musician*" or "piano" or "violin" or "percussion" or "music instrument" or "music performance" or "danc*") or ("education" or "children" or "school" or "kids" or "early childhood education" or "university students" or "university" or "music school" or "students"). It resulted in a total of 1,056 publications which, with the time filter of 10 years, from 2012 to 2022, was reduced to 394. From these, a selection of 251 articles was made and analyzed in more detail.

As we have already explained, although this strategy covered the main axes of the bibliometric study, two additional strategies were designed which were more specific to the field of music in order to find a greater number of results. For this purpose, terms related to education were omitted and the strategy was divided into two fields as follows: [Abstract] "laterality" or ("handedness" or "ambidexterity" or "cross* laterality" or "cross* dominance" or "hand dominance" or "leg dominance" or "eye dominance" or "ear dominance" or "manual preference" or "leg preference" or "eye preference" or "ear preference" or "footedness" or "eyedness" or "earedness" or "lateral preferenc*") and [Abstract] ("piano" or "pianist*") or ("violin" or "violinist*") or ("music" or "musician*") or ("guitar" or "guitarist*") or ("cello" or "cellist*") or ("musical instrument*" or "string instrument*" or "wind instrument*"). The total number of results in this case was 124, which was later reduced to 68 with the time filter. Of these, 38 were selected for the final sample.

The last strategy proposed, which combines laterality and dance, was similar, with laterality and all the concepts related to it on one line and the term "danc*" on another. However, in this case, more importance was given to dance, by searching the abstracts, as opposed to laterality, which was searched using the field referring to the topic. The results were 32 in total, which resulted in 23 publications with the time filter of which 14 were selected for the final sample.

The selection of articles carried out in each of the strategies was based on the following inclusion and exclusion criteria. In reference to search strategy 1, we excluded the articles that appeared due to the use of the term "ambidexterity" but belonged to the field of business and business management. Another term that has not been taken into account is "earedness" in combination with the adjective "open", i.e. "open-earedness". Some publications did include a study of laterality, but most of them did not, referring instead to an individual's ability to be open to other genres or forms in terms of musical preferences.

In addition, the articles that referred to medical pathologies that do not apply to the students found in the different educational stages, such as degenerative diseases or some types of cancer, were not selected. Along the same lines, articles on rehabilitation and preoperative studies were excluded.

As for the inclusion criteria, firstly, all the articles in which a study of laterality was carried out in relation to any stage of the educational system and academic achievement, as well as specific subjects within it, were included. Similarly, as indicated in the search strategy, those articles that related laterality and music have been selected, as this is the area of interest of this study in a more specific way.

Furthermore, regarding the inclusion of specific articles, a number of decisions have been made. It has been decided to include review articles, as well as those which analyze or validate data collection instruments on laterality as they are considered to be of great interest to teachers seeking information on the subject. We have also chosen to include all those dealing with a sample of students with special needs, as well as those in which laterality is not the central focus, but is studied, although to a lesser extent.

Since the heritability of laterality is a matter of debate, we have included articles whose sample is composed of fathers and mothers, and also those with pregnant women where the effects of their behavior during pregnancy on the baby's laterality are studied. Moreover, not only aspects related to pathologies associated with special needs such as autism or ADHD have been taken into account, but also those that relate laterality to psychological factors or mental illnesses such as anxiety or depression, since we can also find such cases in the classroom. It should be noted that articles on the structure of the brain and the limbs of the body have been found, which are included because of their interest for the subject of Physical Education. However, those whose aim was to obtain their exact measurements with respect to the study of their volume have not been included.

The exclusion criteria followed in strategies 2 and 3, which related laterality to music and dance, were two: articles which were related to business were not selected; nor were those which did not study laterality, but focused on the effects of music in general or on balance in the case of dance. Following the establishment of these criteria, which have been delimited on the basis of multiple revisions of the sample, the results of the three strategies were merged into a single list which contained 288 articles. The results were then analyzed in search of duplicates. Four duplicate articles were detected and, likewise, three early access articles were excluded as they were considered to be dated 2023. This resulted in a final sample of 281 documents. For the data analysis the Excel software has been used, which has allowed us to organize the available information extracted from each article into different categories. These correspond to the different variables that we thought worth studying because of their interest for the purposes of this research.

Results

If we look at the distribution by year of the final sample of this study in Figure 1, there are two peaks. The first is in 2015 with a total of 32 documents, nine more than the previous year. From here, the number of publications decreases, reaching in 2019 an amount similar to that of 2012 (n=21) to increase again until the next peak in 2021. In that year there are 30 publications in total, similar to the peak in 2015. And again, this is followed by a decrease in the number of documents published.

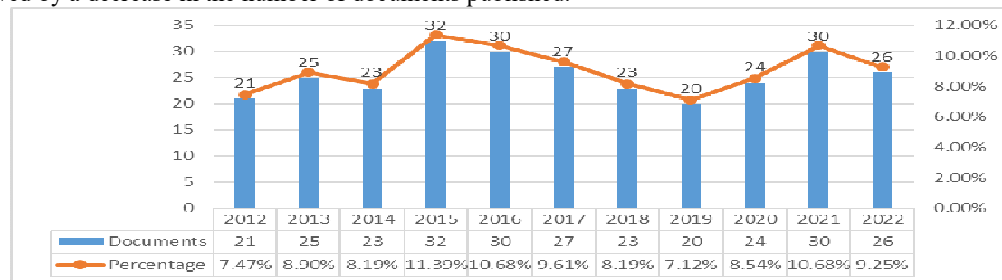


Figure 1. Documents per year

It is possible to compare the trends in the number of publications with the number of citations per year. Figure 2 shows that the peaks regarding documents per year are not consistent with the increasing trend in citations, which reaches its maximum number in 2021 (n=445). Of particular note is the large growth in a matter of 10 years, from 2012 to 2022, which could be explained as a reflection of the growing trend of interest in the topic in the research field.

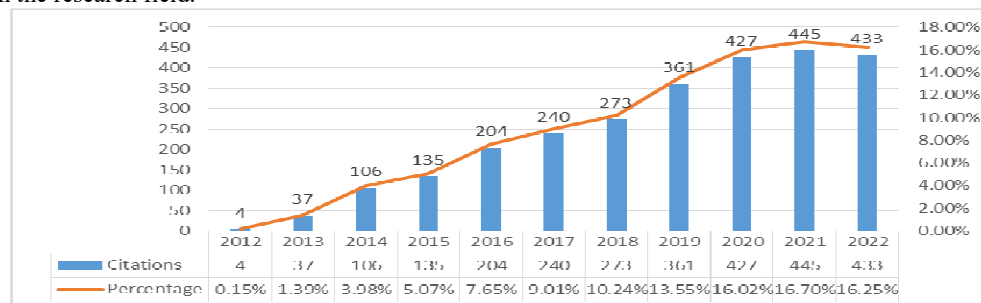


Figure 2. Citations per year

In terms of the language used, publications were found in a total of six languages. According to Figure 3, the language par excellence is English with 94.66% (n=266) of the total number of publications. To a lesser extent, ten articles were written in Spanish, followed by Portuguese (n=2), Russian (n=1), Czech (n=1) and German (n=1).

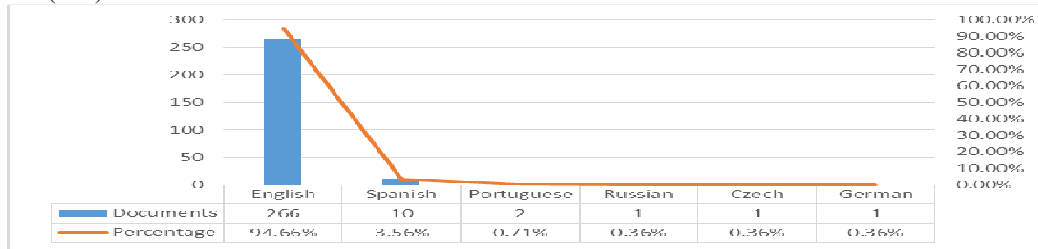


Figure 3. Documents per language

Regarding the type of documents, Table 1 shows that articles constitute the majority of the total sample, 88.26% (n=248), followed by proceeding papers (4.63%, n=13), review articles (4.27%, n=12), and meeting abstracts (1.78%, n=5). Additionally, the treatment of the study area of interest has been analyzed in this article. According to Table 1, laterality is the main object of study in 74.02% (n=208) of the analyzed documents, either in isolation or in combination with other key parameters. This number counteracts with the number of second-order articles, which constitute 22.06% (n=62), and third-order articles which make up 3.91% (n=11).

Table 1. Number of documents per type and treatment order

Type of document	1st order		2nd order		3rd order		Total	
	Docs	%	Docs	%	Docs	%	Docs	%
Article	180	64.06	58	20.64	10	3.56	248	88.26
Editorial Material	1	0.36		0.00		0.00	1	0.36
Letter	2	0.71		0.00		0.00	2	0.71
Meeting Abstract	5	1.78		0.00		0.00	5	1.78
Proceedings Paper	9	3.20	4	1.42		0.00	13	4.63
Review	11	3.91		0.00	1	0.36	12	4.27
TOTAL	208	74.02	62	22.06	11	3.91	281	100

Note: Docs=Documents.

Focusing on the disciplines into which the documents in the sample can be grouped, Figure 4 shows that there are a total of 48 areas. Psychology has the highest number of documents (n=121), followed by neuroscience (n=59) and education (n=22).

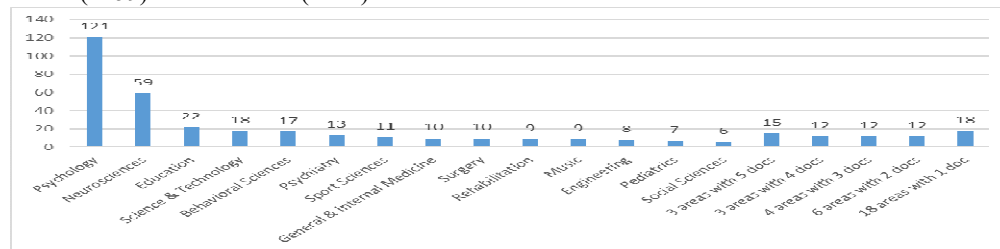


Figure 4. Research areas by number of documents

With regard to the keywords, a total of 781 were used, among which "handedness" and "laterality" stand out in first and second place with 99 and 47 documents respectively, accounting for 35.23% and 16.72% of the sample. Figure 5 shows that the largest number of keywords, 677 out of a total of 781, are used in only one document each.

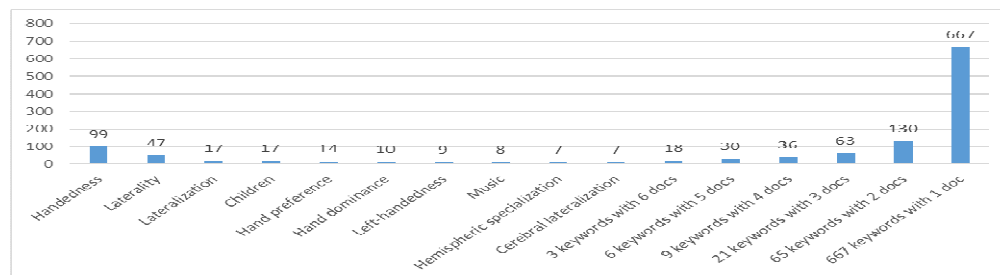


Figure 5. Number of documents per keyword

The fact that the word “handedness” holds the first place is closely related to the type of laterality most studied in the sample. According to Figure 6, 62.44% (n=246) of the documents reviewed focus on handedness, followed by footedness at 13.20% (n=52). Auditory laterality is the least studied type of laterality in education over the past decade, appearing in only 24 documents.

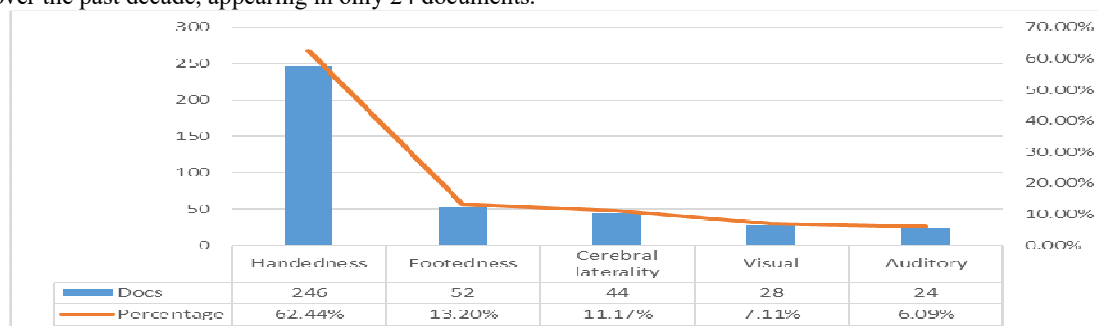


Figure 6. Lateral dominance studied

Table 2 shows that the predominant methodology in the researched documents involving volunteer participants is the quantitative approach, comprising 93.75% (n=240) of the sampled articles. Within this methodology, the majority of studies with these characteristics were intervention-based (59.77%, n=153). The remaining 25 papers not included in Table 2 are research focused on the theoretical foundation of the field. However, an analysis based on the results of a participant sample is not included.

Table 2. Documents ordered by methodology and type of article

Methodology	Documents	%
Quantitative	240	93.75
Theoretical foundation	77	30.08
Intervention	153	59.77
Test validation	10	3.91
Mixed	13	5.08
Theoretical foundation	6	2.34
Intervention	7	2.73
Qualitative	3	1.17
Theoretical foundation	2	0.78
Intervention	1	0.39
TOTAL	256	100

The study of laterality employs diverse test types, with several articles even combining multiple kinds. Despite this, as indicated in Table 3, questionnaires are the most frequently used, appearing in 178 articles, followed by specific tests utilized in 134 articles, including action or exercise performances. There are additional evaluation methods, albeit less prevalent, such as interviews (n=7), rating scales (n=5), and observation (n=5).

Table 3. Types of test used to study laterality

Test	Docs
Questionnaire	178
Specific tests	134
Interview	7
Rating Scale	5
Observation	5

Furthermore, two different approaches have been used to determine the lateral dominance of participants. The first is the use of other authors' questionnaires or test scientifically validated, while the second is the use of newly designed research instruments. Table 4 illustrates that the Edinburgh Handedness Inventory was used in 67 papers, accounting for 20.81% of the total. Secondly, 66 studies (20.50%) relied on self-reported lateral preference information provided by the participants. And thirdly, lateral dominance was investigated through the performance of specific actions in 14.29% (n=46) of the studies.

Table 4. Research instruments used to determine lateral dominance ordered by frequency of use

Instrument	Documents	%
Edinburgh Handedness Inventory	67	20.81
Self-Reported	66	20.50
Actions	46	14.29
Original Questionnaire	18	5.59
Functional Magnetic Resonance Imaging (fMRI)	11	3.42
Dichotic Listening Test	10	3.11
Annett Handedness Questionnaire	9	2.80
Waterloo Handedness Questionnaire (WHQ)	6	1.86
Electroencephalogram (EEG)	5	1.55
Grooved Pegboard Test	4	1.24
Lateral Preferences Inventory	3	0.93
Magnetoencephalography (MEG)	3	0.93
6 different instruments used in 2 docs	12	3.73
62 different instruments used in 1 doc	62	19.25
TOTAL	322	100

Regarding the educational field, three parameters have been analyzed: the educational level of the research participants, the educational subject that some research were related to and the study of Special Educational Needs given its growing importance in education nowadays.

Participants with different levels of education were included in many of the studies reviewed. However, the data presented in Table 5 shows a prevalence of university participants (28.92%), followed by primary school students (26.15%), and early childhood students (12.62%). Some of the articles included in this study also featured samples of adults and families from various age groups, due to the interest in their application to the educational field.

Table 5. Educational level of the participants of the studies

Educational Level	Documents	%
University	94	28.92
Primary School	85	26.15
Early Childhood	41	12.62
Adults	44	13.54
High School	33	10.15
Conservatory	13	4.00
Families	9	2.77
All ages	6	1.85

Table 6 displays the primary educational subjects with which multiple articles in the sample have a direct connection. Some articles even incorporate two different subjects, resulting in 121 articles in total (n=281). The most prevalent subjects are Physical Education and Sports with 23.14% (n=28), Language with 22.31% (n=27), and Music with 21.49% (n=26).

Table 6. Educational subjects addressed in the research

Subject	Documents	%
Physical education (Sports)	28	23.14
Language	27	22.31
Music	26	21.49
Medicine	20	16.53
Dance	12	9.92
Foreign language	4	3.31
Computer science	1	0.83
Engineering	1	0.83
Sign language	1	0.83
Mathematics	1	0.83
TOTAL	121	100

As far as Special Educational Needs are concerned, they are the central subject of 68 documents, which accounts for 24.19% of the sample. Table 6 shows that the most studied are Autism Spectrum Disorder (17.65%, n=12) and Attention-Deficit/Hyperactivity Disorder (ADHD) (13.24%, n=9).

Table 7. Most studied Special Educational Needs

Special Educational Needs	Documents	%
Autism Spectrum Disorder	12	17.65
ADHD	9	13.24
Schizotypy	5	7.35
Deafness	4	5.88
Bipolar Disorder	3	4.41
Focal Epilepsy	3	4.41
6 SEN with 2 docs	12	17.65
20 SEN with 1 doc	20	29.41
TOTAL	68	100

Note: ADHD=Attention-Deficit/Hyperactivity Disorder; SEN=Special Educational Needs

The publishers of the documents of this study are shown in Table 8. Out of a total of 100 publishers, 62 have published only one paper compared to the first four publishers which have 15 or more papers each. Among the publishers listed, Taylor & Francis leads with 35 publications (12.46%), followed by Frontiers Media SA and Sage Publications Inc with 16 and 15 publications respectively, that is 5.69% and 5.34%. The fourth, sixth, and eighth positions are held by three publishers that belong to the same group, Elsevier, an academic publisher from the Netherlands.

These are Pergamon-Elsevier Science Ltd, Academic Press Inc Elsevier Science, and Elsevier Science B.V.

Table 8. Number of documents per publisher

Publisher	Documents	%
Routledge Journals, Taylor & Francis Ltd	35	12.46
Frontiers Media SA	16	5.69
Sage Publications Inc	15	5.34
Pergamon-Elsevier Science Ltd	15	5.34
Wiley	10	3.56
Academic Press Inc Elsevier Science	10	3.56
Springer	9	3.20
Elsevier Science B.V	9	3.20
MDPI	8	2.85
5 publishers with 5 docs each	25	8.90
7 publishers with 4 docs each	28	9.96
5 publishers with 3 docs each	15	5.34
12 publishers with 2 docs each	24	8.54
62 publishers with 1 doc each	62	22.06
TOTAL	281	100

The analysis of the number of documents per country in the sample is based on the countries of origin of the publishers. As illustrated in Figure 7, the total number of countries is 29, with the United States and England holding 95 and 80 documents respectively. It is worth noting that 18 of the 29 total countries belong to Europe, which makes up 62.06%.

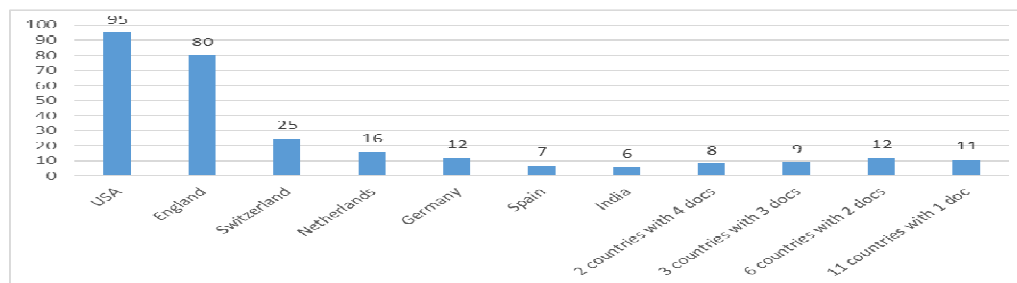


Figure 7. Number of documents per country of publication

In terms of the journals registered, there is a total of 177. The most outstanding is the journal *Laterality: Asymmetries of Body, Brain and Cognition*, published by Taylor & Francis. According to Table 9, it constitutes 10.68% (n=30) of the overall sample. However, it is also noteworthy that 142 articles, which account for 50.53% of the total sample (n=281), were published in a different journal each.

Table 9. Documents per journal

Journal name	Documents	%
142 journals with 1 doc	142	50.53
18 journals with 2 docs	36	12.81
Laterality	30	10.68
8 journals with 3 docs	24	8.54
Frontiers in Psychology	13	4.63
Perceptual and Motor Skills	7	2.49
Brain and Cognition	6	2.14
Neuropsychologia	6	2.14
Plos One	5	1.78
Developmental Neuropsychology	4	1.42
Research in Developmental Disabilities	4	1.42
Scientific Reports	4	1.42
TOTAL	281	100

It is interesting to compare these data with Table 10, which shows the number of citations per journal. Similarly, the journals *Laterality* and *Frontiers in Psychology* are ranked first and second respectively, with *Laterality* having 634 citations (22.32%) and *Frontiers in Psychology* having less than half of that at 149 citations (5.24%).

Table 10. Citations per journal

Journal name	Citations	%
Laterality	634	22.32
Frontiers in Psychology	149	5.24
Neuropsychologia	127	4.47
Neuropsychology Review	118	4.15
Brain Research	86	3.03
Behavioural Brain Research	85	2.99
Brain	80	2.82
Neuroscience and Biobehavioral Reviews	78	2.75
Infant Behavior & Development	70	2.46
Cognitive Science	65	2.29

In terms of authors, there are a total of 1,031 listed. They are grouped into documents whose authorship ranges from a single author to nineteen. Publications with two authors are predominant, accounting for 21% (n=59). In second place are documents with three authors (n=57), and in third place are those with four (n=48), i.e. 20.28% and 17.08% respectively. Figure 8 also shows a decreasing trend in authorship by more than two individuals.

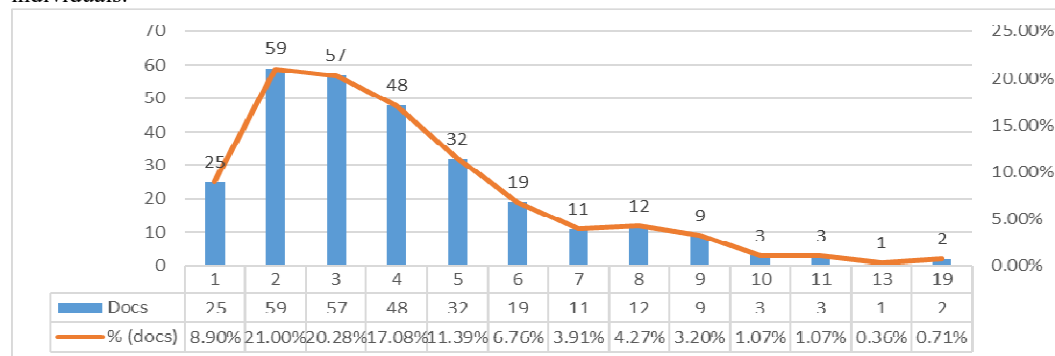


Figure 8. Documents by number of authors

Looking at Table 11 on the number of publications per author, the same trend as in journals and publishers can be observed. Authors with only one publication in the area of study of this article are the most numerous, which contrasts with the highest number of publications by a single author, which is 6 by M. Voracek. In fact, authors who have only contributed one paper in this area comprise 82.67% (n=949) of the total 1,031 authors.

Table 11. Authors ordered by number of documents

Authors	Documents	%
Voracek, M	6	0.52
Tran, US	5	0.44
Teixeira, LA	5	0.44
Papadatou-Pastou, M	5	0.44
Tsuang, HC	4	0.35
Ocklenburg, S	4	0.35
Paracchini, S	4	0.35
Milenkovic, S	4	0.35
Nelson, EL	4	0.35
Forrester, GS	4	0.35
Bryden, PJ	4	0.35
8 authors with 3 publications each	24	2.09
63 authors with 2 publications each	126	10.98
949 authors with 1 publication each	949	82.67

In terms of citations per author, J.F. Veale has the highest number of citations with a total of 325 from a single article, as shown in Table 12. This author is noteworthy since the number of citations from the second author onwards falls significantly, ranging between 100 and 117 citations.

Table 12. Authors ordered by number of citations

Authors	Citations	%
Veale, JF	325	2.77
Nelson, EL	117	1.00
Michel, GF	112	0.95
Lindell, AK	112	0.95
Hudry, K	112	0.95
Campbell, JM	105	0.90
Voracek, M	100	0.85
Tran, US	100	0.85
Forrester, GS	92	0.78
25 authors with citations between 80 and 90	2068	17.63
6 authors with citations between 60 and 79	380	3.24
18 authors with citations between 50 and 59	1012	8.63
10 authors with citations between 40 and 49	433	3.69
21 authors with citations between 30 and 39	730	6.22
73 authors with citations between 20 and 29	1680	14.32
174 authors with citations between 10 and 19	2374	20.24
695 authors with citations between 0 and 9	1878	16.01

As for the documents with the highest number of citations, depicted in Table 13, J.F. Veale's individual publication from 2014 has the most with 325 citations. The second highest, with 112 citations, is an article by two authors, A.K. Lindell and K. Hudry, from 2013. The remaining publications have fewer than 90 citations and are mostly published by research groups, despite the fact that the majority of the studies in the total sample are two-authored.

Table 13. Documents with the highest number of citations

Document title	Citations	%
Veale, J. F. (2014). Edinburgh Handedness Inventory - Short Form: A revised version based on confirmatory factor analysis. <i>Laterality</i> , 19(2), 164-177. 10.1080/1357650X.2013.783045	325	11.44
Lindell, A. K., & Hudry, K. (2013). Atypicalities in Cortical Structure, Handedness, and Functional Lateralization for Language in Autism Spectrum Disorders. <i>Neuropsychology Review</i> , 23(3), 257-270. 10.1007/s11065-013-9234-5	112	3.94
Szaflarski, J. P., Rajagopal, A., Altaye, M., Byars, A. W., Jacola, L., Schmithorst, V. J., Schapiro, M. B., Plante, E., & Holland, S. K. (2012). Left-handedness and language lateralization in children. <i>Brain Research</i> , 1433, 85-97. 10.1016/j.brainres.2011.11.026	86	3.03
Miller, Z. A., Mandelli, M. L., Rankin, K. P., Henry, M. L., Babiak, M. C., Frazier, D. T., Lobach, I. V., Bettcher, B. M., Wu, T. Q., Rabinovici, G. D., Graff-Radford, N. R., Miller, B. L., & Gorno-Tempini, M. L. (2013). Handedness and language learning disability differentially distribute in progressive aphasia variants. <i>Brain</i> , 136, 3461-3473. 10.1093/brain/awt242	80	2.82
Casasanto, D., & Henetz, T. (2012). Handedness Shapes Children's Abstract Concepts. <i>Cognitive Science</i> , 36(2), 359-372. 10.1111/j.1551-6709.2011.01199.x	65	2.29

Forrester, G. S., Quaresmini, C., Leavens, D. A., Mareschal, D., & Thomas, M. S. C. (2013). Human handedness: An inherited evolutionary trait. <i>Behavioural Brain Research</i> , 237, 200-206. 10.1016/j.bbr.2012.09.037	61	2.15
Nelson, E. L., Campbell, J. M., & Michel, G. F. (2013). Unimanual to bimanual: Tracking the development of handedness from 6 to 24 months. <i>Infant Behavior & Development</i> , 36(2), 181-188. 10.1016/j.infbeh.2013.01.009	60	2.11

Discussion

The aim of this study was to conduct a bibliometric analysis of the scientific production on laterality and education published in high-impact search engines during the last 10 years, that is from 2012 to 2022. A sample of $n=281$ articles was collected from the Web of Science search engine. The gathered data is presented in this report with the objective of facilitating future research in this field.

After analyzing the results of this research, it can be stated that the area of study has garnered increasing interest among researchers. Despite a relatively constant number of yearly publications, ranging between 20 and 32 over the past decade, citation numbers demonstrate recent greater usage and access of these research. A clear example is that the number of citations rose from 4 in 2012 to 433 in 2022. However, the exponential increase in citations has not been reflected in the articles published, given that the highest peak of annual publications was in 2015 ($n=32$) and, in contrast, between 2021 and 2022 there was a slight drop from 30 to 26 publications.

It is interesting to establish a relationship between the increase in the number of annual citations and the most cited articles from the sample. As shown in Table 13, the articles with the highest number of citations, and subsequently, the greatest impact, were published between 2012 and 2014. During this period, the number of citations and interest in the subject matter experienced a significant growth, resulting in a substantial transformation. For these reasons, it can be affirmed that despite the decrease in the number of publications between 2015 ($n=32$) and 2019 ($n=20$), there was still a growing interest in the field of study, with a rise in citations from 135 in 2015 to 361 in 2019 and a peak of 445 in 2021. This supports Ocklenburg's (2020) assertion that the 2010s heralded significant developments in laterality research in general which we also see reflected here, albeit to a lesser degree, in its relation to education.

Furthermore, the vast majority of publications are written in English, despite the fact that it is not the mother tongue of many authors. This is mainly due to two factors. On the one hand, to its consideration as the *lingua franca* in the world in general and in the scientific community in particular and, on the other hand, it can be attributed to the fact that the publishers par excellence in the sample are from the United States (33.81%, $n=95$) and the United Kingdom (28.47%, $n=80$). Despite this, the scarcity of literature in Portuguese and German is striking, especially since they, along with the French school, have been the foremost pioneers in the study of laterality. Nevertheless, we can attribute this observation to the need for a greater international projection of their research. As noted earlier, the majority of the documents are articles, accounting for 88.26% of the total sample ($n=281$). Of these, 74.02% are classified as first order studies in terms of the importance assigned to laterality. However, only 22.06% ($n=62$) are second-order studies, while 3.91% ($n=11$) are third-order studies, which consider laterality as an additional variable. The latter studies were published after 2018. This suggests that given its increasing relevance in the previous years, some authors have started including laterality as a variable in their studies, which in some cases has led to interesting new results in the educational field.

With regard to the areas of study, education is not the primary thematic area of the sample, but it is one of the main axes of this bibliometric review. In fact, it comes in third place and represents 7.82% ($n=22$). The reason for this is because, on several occasions, due to the type of sample used for the research, some documents are not considered to be directly related to the field of education in the search engine database.

Psychology and neuroscience are the dominant areas with 43.06% ($n=121$) and 20.99% ($n=59$) respectively. Indeed, laterality is a research topic that piques interest across multiple disciplines. Psychology and neuroscience, which also conduct research of significant interest to the educational field, are intertwined with this topic. As shown in Table 6, a total of 121 articles deal with different educational subjects in isolation or combined. Many of them pertain to higher education, which is also the most frequently used student group in the participants' samples. Music and medicine are the most commonly studied areas at this educational level. In the documents of this sample, music ($n=26$) has been studied from two points of view. On the one hand, investigating laterality and music in general ($n=15$, 57.69%), and the performance through a particular instrument ($n=11$, 42.30%). However, this field has not been investigated in depth since, despite laterality being present in the technique of every instrument, it has only been studied with piano players. In the case of medicine ($n=20$), laterality has been examined in terms of dexterity with different medical instruments and, more specifically, in the specialties of dentistry, gynecology and surgery.

As we have analyzed previously, as far as research methodology is concerned, the quantitative method is predominant at 93.75% and, more specifically, intervention studies at 59.77%. As a result, the most frequently used data collection tools are the questionnaire and the performance of specific actions and exercises. Interviews, which are also an important research tool are not relevant in this context due to the intrinsic characteristic of the laterality of movement.

The most investigated laterality in the sample is handedness (62.44%), followed by footedness (13.20%) and cerebral laterality (11.17%). Consequently, the most frequently used instruments for data collection can be grouped according to these parameters. In the case of manual laterality, already scientifically proven instruments have been used, such as the Edinburgh Handedness Inventory, the Annett Handedness Questionnaire and the Waterloo Handedness Questionnaire. In the case of cerebral laterality, medical tests such as the Functional Magnetic Resonance Imaging, the Electroencephalogram or the Magnetoencephalography have been used. However, it is noteworthy that in 23.48% of the total sample (n=281) the authors preferred to ask the participants about their dominant side and then carry out tests based on this response. Moreover, the majority of articles investigating auditory laterality utilized the Dichotic Listening Test, which accounted for 41.66% of all studies on this type of laterality (n=24). In the present sample there is a tendency to investigate multiple types of laterality in the same study in order to establish a relationship between their results. While most of them focus on one type (n=202, 71.89%), there are also articles that examine up to five types of laterality. A 21% (n=59) of the articles study two types, a 4.27% (n=12) research four types of laterality, a 2.49% (n=7) consider three types and, finally, only one article investigates (0.36%) five types, that is, including the study of cerebral laterality through medical imaging tests. Concerning the journals where the publications are collected, the journal *Laterality* outstands for being the one with the highest number of articles published, with 10.68% (n=30) of the total sample. Founded in 1996, *Laterality* is a specialized journal that studies laterality in human and non-human species and its psychological, behavioral, neuronal and genetic manifestations. However, despite this, it is striking that it does not have a higher number of publications with respect to the total number of documents (n=281). This can be attributed to the fact that education is not one of its primary areas of focus. The other main journals are from the fields of psychology and neuroscience (*Frontiers in Psychology*, *Brain and Cognition*, *Neuropsychologia* and *Developmental Neuropsychology*), with one particular journal concentrated on motion, *Perceptual and Motor Skills*, a 1949 journal devoted to new science in learning, memory, executive functioning, perception, and motor skills. Considering that, together with *Laterality*, these are journals focused on the topic of this article, the fact that there are not a greater number of publications on the relationship between laterality and education indicates that it has not been a topic of scientific interest until recently.

On the authorship of the documents of the sample, it is notable that there is not a certain group of authors with a significant number of publications on this subject. This indicates the lack of an established research field linking laterality and education and highlights the need for further investigation, as evidenced by the fact that the vast majority of authors of the sample (82.67%, n=949) have only published one article, either alone or together in a research group. M. Voracek and U.S. Tran are the authors with the highest number of publications, with 6 and 5 respectively. As a matter of fact, they have collaborated on five of these publications. Three of them are characterized by a focus on the study of footedness, while the remaining analyze latent variables based on the observation of observable variables, specifically the lateral preference of hands, feet, eyes and ears. Hence, they can be considered to have a certain degree of expertise in the subject. These data contrast with the number of citations per author. Despite being the two authors with the most publications, their articles have not had as much impact. In this regard, J.F. Veale stands out, who achieved 325 citations with a single article on laterality. In the case of E.L. Nelson, it is possible to establish a correlation between the documents published (n=4) and the number of citations (n=117). Even so, these cases are uncommon, as the great majority of authors, a 67.41% (n=695), have obtained between 0 and 9 citations. Finally, it is interesting to analyze the topics covered by the most cited articles of the sample in relation to the main trends in the study of laterality and education. The aforementioned most cited study, by J.F. Veale and published in 2014, analyzes the most widely used questionnaire to collect data on manual laterality, the Edinburgh Handedness Inventory. This is probably the reason why it takes this position; given that it combines the verification of a widely used questionnaire with the study of the most investigated type of laterality. The following three articles from 2012 and 2013 discuss the relationship between language and cerebral and manual laterality. In fact, the second most cited article, by A.K. Lindell and K. Hudry, examines language lateralization and its connection to manual laterality in individuals with autism. This is consistent with the central axes found after the analysis of the data collected in this study, which argue that manual laterality is the most studied, language is one of the subjects to which research articles on laterality and education have been associated the most, and there is a growing interest in the study of laterality and its evolution in both general and special needs population.

Conclusions

Some of the main limitations encountered in the study process of this article are, on the one hand, the use of data collected from a single search engine, and on the other hand, the complexity of carrying out an analysis of predominantly medical-related articles. The selection of this search engine was based on the accuracy of the subject matter and the quantity retrieved, as well as the existence of a subject area in Web of Science dedicated to education which is absent in other search engines such as Scopus. As for medical terminology, specialized reference works in this field have been used. Another limitation has been the lack of precision in some studies whose central area was not laterality but did appear as another variable to be taken into account, due to a lack of information on the specifics of how the data was collected.

Given the significance of laterality in the motor, cognitive and emotional development of individuals, understand it and study how to develop it along the learning process in the classroom is vital. This is because it has already been demonstrated that it has a direct effect on academic performance and the holistic development of students. Likewise, an understanding of laterality allows educators to recognize and comprehend the specific characteristics of their students, adapting their pedagogical approaches and learning materials to address these needs, resulting in a more personalized and efficient instruction. From the student's perspective, self-knowledge enhances the development of motor skills and coordination and, consequently, better control of the body and greater dexterity in activities such as writing, drawing, playing sports, using tools, and dancing. Additionally, the study of laterality helps to identify potential motor difficulties allowing for early intervention if necessary.

Therefore, conducting studies with control and experimental groups to investigate differences in children's developmental levels at various educational stages through the implementation of specific activities for developing laterality would be beneficial. Similarly, and due to the increasing number of diagnosed cases of students with special needs, it would be interesting to explore the benefits that an education centered on the development of laterality could bring to the overall development of the individual.

In conclusion, this study not only aims to present an overview of the scientific production published in high-impact search engines for future research, but also to raise awareness of the importance of incorporating laterality in the educational community. This can be achieved by educating professionals and explicitly including laterality in educational curricula since the development of laterality from an early age could have a significant positive impact on the overall development of the human being.

This publication belongs to the academic programme of the BAPNE method which has an official research group called Neuromotricity and motor literacy of the University of Alicante, which currently has more than 3000 academic citations and a high number of publications in Web of Science and Scopus. Figure 9 shows the number of publications in the web of science.



Figure 1. Publications of the BAPNE method in Web of Science

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