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Progress and Trends of Affective Prosody Research over 25 Years: A Bibliometrics-Based Visualization Analysis (1997–2021)

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Abstract: Affective prosody is an indispensable cognitive cue that moderates social activities, and has become a prevailing research topic in psychology-related disciplines. The present study conducts the first bibliometrics-based visualization analysis concerning affective prosody to evaluate the influential cases, including countries/regions, institutions, publication venues, academic articles, and disciplinary contributions, and the diachronic changes of publication trends and research hotspots. With the combination of statistical results and a qualitative literature inspection, limitations of extant studies and promising research directions were also proposed. The present study extracted the bibliographic data of 1,624 articles retrieved from the Web of Science Core Collection, which were published over the past 25 years (1997-2021). Statistical results revealed four leading powers (the U.S., Germany, England, and Canada) and four emerging fronts (China, France, Netherlands, and Switzerland), and identified three primary research themes in this field, including clinical implication, measurable index, and modality-specific issues. Literature inspection demonstrated current limitations in individual characteristics control and experiment-related influential factors, and proposed two prosperous research directions. Findings of the present study could facilitate academic retrieval of affective prosody research, help concerned researchers identify thematic hotspots and seek appropriate collaboration, and provide convenience for research policy and management in this field.

Keywords: affective prosody; bibliometric analysis; research impact; research trend; thematic hotspots

1. Introduction

Speech prosody carries the grammatical, pragmatic and emotional messages in daily communication (Pell et al., 2015), which can be divided into linguistic and paralinguistic prosody (Grice & Baumann, 2008). Linguistic prosody provides additional lexical, syntactic, and pragmatic messages so that this type of prosody can correspondingly indicate changes of parts of speech, resolve syntactic ambiguity, and differentiate statements from questions. The paralinguistic prosody usually denotes the affective function of speech prosody, which can reflect individuals' mental states (Paulmann et al., 2016) and promote contextualization in interpersonal engagement and social interaction. Over the past decades, a considerably increasing body of research has achieved progress concerning speech prosody. In the psycho-linguistics field, researchers are especially interested in affective prosody due to its convenient interaction with other information delivery channels (e.g., facial expression and semantics) and the ensuing competence for cognitive resources (Pell et al., 2011). Hence, periodically retrospective analyses on affective prosody research are in prompt demand.

Affective prosody, as a superordinate term, contains two subordinate prosody types, that is, the emotional prosody and attitudinal/intellectual prosody (Ross, 2000). Extant affective prosody research has mainly focused on the emotional aspect compared to the attitudinal aspect, and some research even interchangeably used these two subordinate notions. Indeed, the prosody features used

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in the expressions of both prosody are quite similar, such as changes in pitch, rhythm and amplitude, and the relevant acoustic correlates for emotional and attitudinal prosody discrimination are also partially overlapped. However, as suggested by Mitchell and Ross (2013), attitudinal prosody is fundamentally different from emotional prosody, and this attitudinal aspect of affective prosody deserves greater attention and concentrated research on its own. Prior studies suggested the specific prosody type be discerned at a definition level and a perception level (Grichkovtsova et al., 2012; Scherer, 2003). By definition, "emotion" is an involuntary but intense form of affects, whereas "attitude" is an intentional and enduring presentation of affects. As for perception, emotional prosody, especially the basic emotions, can be universally identified and relies on the voice quality, whilst the attitudinal prosody embodies the social and cultural beliefs and relies more on the prosody contour. Considering the significance of both aspects of affective prosody in academic research, we include publications related with either topic in a comprehensive reflection for this field in the current study.

Over the years, affective prosody has aroused an increasing interest among researchers from various disciplines, and corresponding research topics have become the mainstream in this field. In the psycho-linguistics discipline, the production and perception of affective prosody, in contrast to the other forms of speech prosody have been commonly investigated. For instance, with the Stroop paradigm, a body of research examined the dominant perceptive channels (semantics or prosody) in multi-modal information processing (Lin et al., 2020). Over recent years, in response to the shortcomings of static and single-modal emotion presentation, such as authenticity and partial activation of executive function, researchers have drawn more attention to the audiovisual stimuli and the function of affective prosody in social communication. As for the neuropsychological discipline, the brain activation and clinical impairments of affective prosody also play an essential role. For one thing, fundamental research has extensively explored the hemispheric lateralization and neural networks of affective prosody (Durfee, Sheppard, Blake et al., 2021; Witteman et al., 2011). For another, clinical research either directly documented the outcomes of prosody-failure illnesses, such as aphasia and aprosodia (Benedetti et al., 2021), or revealed the functional deficits of affective prosody ability in patients with mental disorders, such as bipolar and depression disorders (Tang et al., 2022). Besides these two psychology-related disciplines, affective prosody also showed its presence in computer science and engineering. For instance, the analyses and composition of the acoustic information extracted from humans' affective prosody can be used to establish automatic affective speech databases, design humanoid robots and modify acoustic parameters of hearing aids.

Considering the cross-disciplinary academic and practical significance of affective prosody, a periodical review and bibliometrics-based visualization on the evolution and progress of this field is promptly needed. Bibliometrics-based research serves as an efficient tool to review the scientific production and thematic trends in a given research field. The present study adopted this approach to analyze the influential cases and visualize the diachronic changes of affective prosody research, and summarized the existing limitations with an in-depth inspection of the publications. To be more specific, influential case analyses covered the most productive countries/regions, academic institutions, publication venues, and the most cited academic articles. In addition, the contribution of relevant findings in different disciplines was also ranked to reveal the corresponding relevance. As for the diachronic changes, a series of analyses, including the publication trends, fluctuation of research themes, and the identification of research hotspots, were conducted. The bibliometric mapping of these two research concerns would provide a comprehensive insight for interested researchers, and facilitate academic communication and scientific retrieval. To enhance the value in affective prosody-related research design and scope, a summary of limitations in methodology was also proposed, accompanied with the characteristics of recently most cited publications and future research directions in this field.

Although affective prosody research has achieved fruitful outcomes and has been integrated in a few systematic reviews and meta-analyses, no bibliometric study has been conducted in this field. Therefore, it is of great theoretical and practical necessity to evaluate the scientific developments and current status of affective prosody research over the past decades (1997-2021). There are three

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objectives in the present study. First, we analyzed the influential cases to depict the current situation of this field. Second, we tracked the diachronic changes to reveal the emerging research fronts and important thematic trends. Third, we combined statistical results with literature analysis, and specified existing limitations and promising research directions. As the first bibliometrics-based visualization study in the affective prosody field, it can provide convenience for concerned researchers to identify meaningful topics and seek appropriate collaborations, and also shed lights on relevant research policy and management.

2. Methods

In this section, analytical tools and assessment indices for the present study are described.

2.1. Data retrieval and extraction

The Web of Science (WoS) Core Collection, one of the primary and largest bibliographic databases, was retrieved on January 14, 2022. As this database includes a substantial range of major academic journals, it has been widely used in previous bibliometric research across various disciplines (Li et al., 2022; Li & Lei, 2021). Furthermore, the WoS Core Collection also provides detailed bibliometric information on academic articles, such as the authors, abstracts, journals, and citation counts, which warrants a collective investigation in the present research.

Following the research kernel, research articles relevant to affective prosody that were published in English in this database were searched from the earliest inclusion year to the end of 2021. All articles with "affective prosody" OR "emotion* prosody" terms in the title, abstract or keywords were retrieved. Limited to the inclusion periods of WoS, the earliest publication year for included articles was 1997, thus leading to a 25-year span for the current bibliometric investigation of this topic. Articles without an abstract were eliminated, and a total of 1,624 entries were enrolled for further analyses. A set of major bibliographic information was extracted, including the article titles, authors, abstracts, journals, keywords, publication year, and citation counts. A manual examination ensured that all missing items were accurately supplemented for follow-up investigations.

2.2. Data analysis

In general, the current bibliometric study used Python (Version 3.9.9) and R (Version 4.0.3) to analyze multiple variables pertaining to research questions. VOSviewer (Version 1.6.17) (van Eck & Waltman, 2010; Waltman et al., 2010) was also used to cluster the keywords.

The clout of countries/regions, research institutes, and publication venues were counted by the number of aggregated journal articles. The impact of academic articles was evaluated by their citation counts. However, due to the different access duration of each article, the raw citation counts fall short of direct comparability. Hence, a normalization approach was taken by formula (3), that is, to divide the raw citation counts of certain articles into the total number of citations in the corresponding publication year, as in prior bibliometric studies (Li & Lei, 2021).

$$Normalized\ Citation = \frac{Raw\ Citation\ of\ an\ article}{Total\ citation\ counts\ in\ the\ publishing\ year} \quad (3)$$

Diachronic research changes in this field mainly focused on yearly publication number and research themes. By calculating the number of published articles in each year over the concerned time span, the tendency of research interest was illustrated in a macroscopic way. Furthermore, an examination of hot and cold research themes in this field can statistically specify valuable and disputable topics under intense investigation, which can be primarily manifested by keywords and abstracts. Therefore, in addition to a keyword analysis, the research themes were extracted and analyzed by a four-step dependency-based method (Lei et al., 2020). First, since most parts of speech like verbs, adverbs, and adjectives cannot individually function as topics (Lei & Liu, 2019), all downloaded abstracts were submitted to the *noun_chunks* function of *Spacy* so that elementary noun

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phrases (two-word and larger bundles) were automatically obtained based on the syntactic dependency relation parsing. Second, the cut-off frequency and dispersion threshold were valued as the criteria for identifying significant research topics. As noticed, since the length of noun phrases could influence the other two standards in that monograms and bigrams were found less frequent than multigrams, it has been suggested that different inclusion bars should be set based on the length of phrase (Huan & Guan, 2020). Considering the inconsistency in defining the thresholds, we adopted previous considerations (Lei et al., 2020) and conducted several rounds of experiments to identify an appropriate criterion for frequency and dispersion range. As a result, a minimum frequency of 30 times and a minimum dispersion threshold of 30 texts were set for monograms and bigrams, while that of 20 times and 20 texts for multigrams. The third step included subjective assessments for statistically qualified noun phrases to be marked as research topics in this field. Based on the previously proposed criteria (Huan & Guan, 2020; Lei et al., 2020; Lei & Liu, 2019), noun phrases were not considered as research topics if (1) the noun phrase was too normal in general use (e.g. *a group*, frequency: 38; dispersion: 38); (2) the noun phrase was normally applicable to most research fields, though not in general English use (e.g. *this study*, frequency: 208, dispersion: 194); (3) the noun phrase was too narrow to be only regarded as a research concern in specific research directions subordinate to the general affective prosody field (e.g. *early stage*, frequency: 27, dispersion: 16). Afterwards, one linguistic professional (HD) and two graduates (ET, XF) individually labeled the noun phrases, and a lenient selection strategy was carried out throughout to moderate the subjectivity bias (Huan & Guan, 2020; Lei et al., 2020). As for inconsistent labels, agreements were reached after discussion. Fourth, the hot and cold research topics were identified by a time series regression analysis. The relatively stationary and comparable normalized dispersion frequency was used in further calculation, which was obtained based on formula (4). The AR(1) autoregressive model (Fang et al., 2018) was fit by the packages *forecast* and *lmtest* for each research topic to depict the corresponding trends, thus indicating whether the topic is becoming hotter or colder over the past 25 years.

$$Normalized\ Yearly\ Dispersion = \frac{Raw\ yearly\ dispersion\ of\ a\ noun\ phrase}{Yearly\ number\ of\ abstracts} \quad (4)$$

3. Results

Results of influential cases and diachronic research trends were reported in separate sections.

3.1. Influential cases

3.1.1. Influential countries/regions

The present study attributes the regional clout to the correspondence address, which represents the most direct stakeholder of corresponding articles that essentially undertakes the accountability. Therefore, the regional distribution was depicted by pooling the country or region information of the affiliated institution of each corresponding author and then calculating the proportion of each region out of the pool. Since an author can be affiliated to more than one institution, 1784 indices were collected in the pool. In addition, a broad all-author calculation for regional distribution was also carried out to collectively measure the contribution of all geographical regions reflected by the institutions of all authors.

The top 15 most influential countries/regions are illustrated in Figure 1, where CorCNT means the count by correspondence and Non-CorCNT means the difference between all-author counts and CorCNT. According to the CorCNT, the five most influential countries atop the list are the U.S., Germany, England, Canada, and Mainland China, which together account for more than half of the total publication number. Altogether, these 15 most productive countries published 83.47% of articles in the affective prosody field over the past 25 years. The total correspondence count of China virtually consists of Mainland China (98) and the Taiwan region of China (14), thus remaining the 5th position on the chart with an aggregation of 112 (6.28%) published articles. Moreover, the frequency count based on the institutional information of all authors elicited a similar rank. With such an analysis,

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Belgium should also be identified as one of the most influential countries, for it has been recognized as the correspondence address 26 times (1.46%, Rank 16) with 66 institutions (Rank 15) that have taken part in relevant experiments.

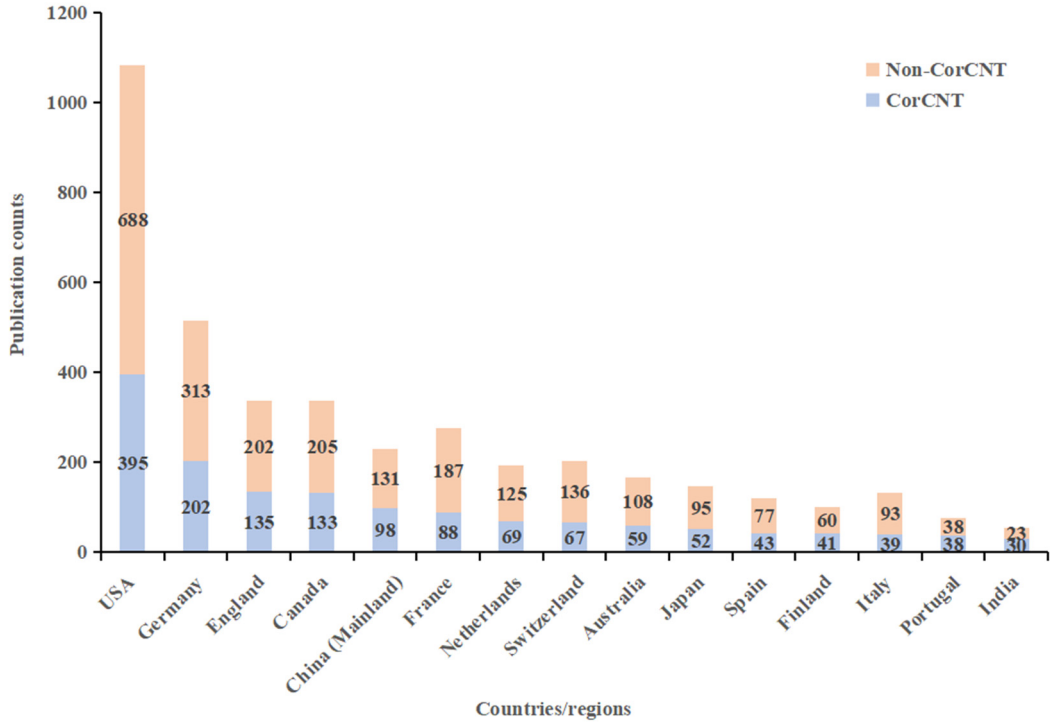

Figure 1. Most influential countries/regions ranked by the count of first-author publications.

3.1.2. Influential institutions

As each author's contribution leads to the findings of each article, the present study indexed the institutional information of all authors to measure the academic influence. Institutions that have published no fewer than 30 articles in the field of affective prosody are presented in Table 1. Among these institutions, the Max Planck Society is a research organization consisting of multiple sectors, which includes several subordinate institutes (MPI) in the present study, such as MPI for Human Cognitive and Brain Sciences (68 author counts), MPI for psycholinguistics (8) and MPI for Empirical Aesthetics (6). In general, American institutions (6) seem to play one of the most important roles, followed by Canada (2), England (2), Germany (2), Netherlands (2), and Switzerland (1), which ranks similarly as the most influential countries.

Table 1. Top 15 Most influential academic institutions.

Rank	Institutions	Countries	AllCNT
1	University of Geneva	Switzerland	121
2	Mcgill University	Canada	114
3	Max Planck Society	Germany	90
4	University of Tübingen	Germany	76
5	University College London	England	51
6	University of Florida	USA	49
6	University of Toronto	Canada	49
8	University of Oklahoma	USA	41
9	Harvard University	USA	40
10	University of Essex	England	37
11	Johns Hopkins University	USA	36

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11	University of California Los Angeles	USA	36
13	Leiden University	Netherlands	34
14	University of Groningen	Netherlands	32
15	University of Pennsylvania	USA	30

* AllCNT = count by all authors.

3.1.3. Influential publication venues

Among 475 academic journals that have published research about affective prosody, the most influential 22 journals with at least 15 publications are presented in Table 2, which contribute to 35.60% of the total publications. In terms of research discipline, the areas with the highest proportion are Neurosciences (11/22), followed by Psychology-Experimental (8/22), Behavioral Sciences (3/22), Psychiatry (3/22), and Psychology (3/22). Other research areas, such as Linguistics, Neuroimaging, Radiology, Nuclear Medicine & Medical Imaging, Clinical Neurology, and Computer Science, are also important disciplines related with affective prosody. As for journal impact factor (2020), the top three journals are *Neuroimage* (6.556), *Behavior Research Methods* (6.242), and *Cerebral Cortex* (5.357).

Table 2. Most productive publication venues.

Rank	Publication sources	PU	PE	IF (2020)	CA
1	Neuropsychologia	52	3.20	3.139	Psy-EX; NeuroS; BehavS
2	PLoS One	42	2.59	3.240	MultiS
3	Frontiers in Psychology	41	2.52	2.988	Psy-Mul
4	Speech Communication	39	2.40	2.017	CS-IA; Acou
4	Schizophrenia Research	39	2.40	4.939	Psych
6	Neuroimage	38	2.34	6.556	NeuroS; RNMMI; NeuroI
7	Brain and Language	35	2.16	2.381	Psy-EX; Ling; NeuroS
8	Psychiatry Research	30	1.85	3.222	Psych
9	Social Cognitive and Affective Neuroscience	25	1.54	3.436	Psy-EX; NeuroS; Psycho
10	Journal of Speech Language and Hearing Research	24	1.48	2.297	Ling; Rehab
11	Cognition & Emotion	23	1.42	2.678	Psy-EX
12	Frontiers in Human Neuroscience	22	1.35	3.169	NeuroS; Psycho
13	Cortex	21	1.29	4.027	Psy-EX; NeuroS; BehavS
14	Emotion	18	1.11	4.329	Psy-EX
14	Brain and Cognition	18	1.11	2.310	Psy-EX; NeuroS
16	Scientific Reports	17	1.05	4.380	MultiS
16	Journal of the International Neuropsychological Society	17	1.05	2.892	NeuroS; Psycho; ClinicN; Psych
18	Human Brain Mapping	16	0.99	5.038	NeuroS; RNMMI; NeuroI
18	Cognitive Affective & Behavioral Neuroscience	16	0.99	3.282	NeuroS; BehavS
20	Behavior Research Methods	15	0.92	6.242	Psy-Math; Psy-EX
20	Journal of Nonverbal Behavior	15	0.92	2.938	Psy-Soc
20	Cerebral Cortex	15	0.92	5.357	NeuroS

* PU = publications; PE = percentage; IF = impact factor; CA = category; Psy-EX = Psychology, Experimental; NeuroS = Neurosciences; BehavS = Behavioral Sciences; MultiS = Multidisciplinary Sciences; Psy-Mul = Psychology, Multidisciplinary; CS-IA = Computer science, Interdisciplinary applications; Acou = Acoustics; Psych = Psychiatry; RNMMI = Radiology, Nuclear Medicine & Medical Imaging; NeuroI = Neuroimaging; Ling = Linguistics; Psycho = Psychology; Rehab = Rehabilitation; ClinicN = Clinical Neurology; Psy-Math = Psychology, Mathematical; Psy-Soc = Psychology, Social.

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3.1.4. Influential articles

The influence of publications is measured by the normalized citation counts, that is, the proportion that the raw citation counts of one particular article take account of the total citation counts in the identical year. The most cited 20 articles are listed in Table 3. By and large, seven articles were published between 1997 and 1999, nine articles were published between 2000 and 2009, and four articles came out between 2010 and 2021.

Table 3. Top 20 most cited articles.

Rank	Authors	Year	Title	Journals	RC	NC
1	Morris, Scott & Dolan	1999	Saying it with feeling: neural responses to emotional vocalizations	*Neuropsychologia*	180	0.3273
2	Buchanan, et al.	2000	Recognition of emotional prosody and verbal components of spoken language: An fMRI study	*Cognitive Brain Research*	335	0.2980
3	Borod, et al.	1998	Right hemisphere emotional perception: Evidence across multiple channels	*Neuropsychology*	374	0.2926
4	Imaizumi, et al.	1997	Vocal identification of speaker and emotion activates different brain regions	*Neuroreport*	131	0.2220
5	Edwards, et al.	2001	Facial affect and affective prosody recognition in first-episode schizophrenia	*Schizophrenia Research*	350	0.2193
6	Hooker & Park	2002	Emotion processing and its relationship to social functioning in schizophrenia patients	*Psychiatry Research*	335	0.2192
7	Adolphs & Tranel	1999	Intact recognition of emotional prosody following amygdala damage	*Neuropsychologia*	120	0.2182
8	Laukka & Elfenbein	2021	Cross-cultural emotion recognition and in-group advantage in vocal expression: A meta-analysis	*Emotion Review*	18	0.2118
9	El Ayadi, Kamel & Karray	2011	Survey on speech emotion recognition: Features, classification schemes, and databases	*Pattern Recognition*	910	0.2097
10	Grandjean	2021	Brain networks of emotional prosody processing	*Emotion Review*	16	0.1882
11	Salmelin, et al.	2000	Single word reading in developmental stutterers and fluent speakers	*Brain*	201	0.1788
12	Shriberg, et al.	2001	Speech and prosody characteristics of adolescents and adults with high-functioning autism and Asperger Syndrome	*Journal of Speech Language and Hearing Research*	274	0.1717
13	Pell & Baum	1997	The ability to perceive and comprehend intonation in linguistic and affective contexts by brain-damaged adults	*Brain and Language*	94	0.1593
14	Hollander, et al.	2007	Oxytocin increases retention of social cognition in autism	*Biological Psychiatry*	514	0.1561
15	Pell & Baum	1997	Unilateral brain damage, prosodic comprehension deficits, and the acoustic cues to prosody	*Brain and Language*	86	0.1458
16	Glasser & Rilling	2008	DTI tractography of the human brain's language pathways	*Cerebral Cortex*	425	0.1373

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17	Cadieux & Greve	1997	Emotion processing in Alzheimer's disease	*Journal of the International Neuropsychological Society*	76	0.1288
18	Pourtois, et al.	2000	The time-course of intermodal binding between seeing and hearing affective information	*Neuroreport*	143	0.1272
19	Poole, Tobias & Vinogradov	2000	The functional relevance of affect recognition errors in schizophrenia	*Journal of the International Neuropsychological Society*	141	0.1254
20	Piazza, et al.	2020	Infant and adult brains are coupled to the dynamics of natural communication	*Psychological Science*	36	0.1237

* RC = raw citation; NC = normalized citation.

3.1.5. Disciplinary contribution

Articles related to affective prosody have contributed to 68 subject categories in general, and the 15 most contributory subjects are presented in Table 4. Since one article may report advanced findings facilitating the understanding of affective prosody in more than one subject category, the total counts of all categories exceed the number of included articles. Based on the statistics, this research topic has aroused attention from multiple scientific fields, which has been calling for more interdisciplinary collaborations. In general, most affective prosody studies contributed to the area of Science Technology (1234), followed by Life Sciences (977), Social Sciences (824), Technology (208), Arts Humanities (33), and Physical Sciences (4). Specifically, the five most contributory disciplines were Psychology (665, 40.95%), Neurology (616, 37.93%), Psychiatry (230, 14.16%), Linguistics (212, 13.05%), and Audiology Speech Language Pathology (154, 9.48%).

Table 4. Top 15 most contributory disciplines of affective prosody.

Rank	Subject categories	Publications	Percentage (out of 1624)
1	Psychology	665	40.95
2	Neurosciences Neurology	616	37.93
3	Psychiatry	230	14.16
4	Linguistics	212	13.05
5	Audiology Speech Language Pathology	154	9.48
6	Computer Science	129	7.94
7	Behavioral Sciences	127	7.82
8	Rehabilitation	97	5.97
9	Science Technology Other Topics	84	5.17
10	Engineering	76	4.68
11	Acoustics	75	4.62
12	Radiology Nuclear Medicine Medical Imaging	55	3.39
13	Otorhinolaryngology	37	2.28
14	Education Educational Research	26	1.60
15	Geriatrics Gerontology	19	1.17

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3.2. Diachronic trends

3.2.1. Publication trend

The number of annual publications in the field of affective prosody is plotted in Figure 2, and a linear regression model was fit to illustrate the general tendency. The observable overall increasing trend (R-squared = 93.53%) indicates that affective prosody has attracted an increasing attention from more researchers over the past 25 years.

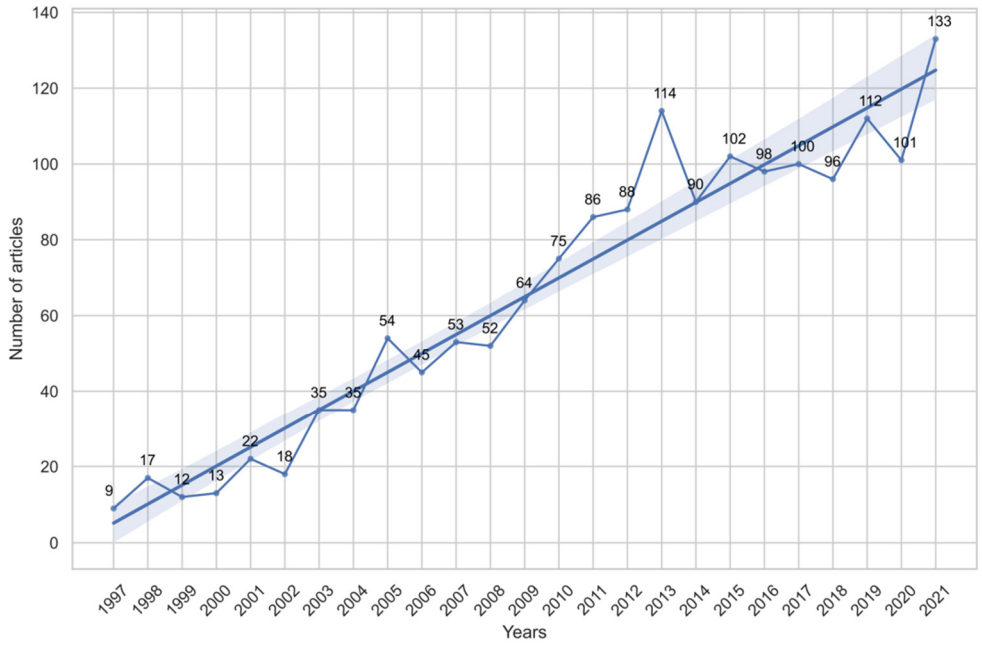

Figure 2. The number of annual affective prosody related publications.

3.2.2. Research themes

As research themes can be reflected from keywords and abstracts, the results of both analyses were reported. Keyword co-occurrence was analyzed to effectively determine major research domains, emerging trends, and global hotspots. There were 3,068 keywords totaling 136 keyword clusters that occurred at least once among all included articles, sixteen of which appeared more than 100 times. However, a low frequency may lead to a low interpretive power and further blur the clustering result, so the present study only aggregated keywords that occurred at least 10 times. Results show that a total of six clusters with 76 keywords were identified and the visualization map is illustrated in Figure 3. Keyword clusters consist of mental disorder (#1, 15 items), multi-modal representation (#2, 13 items), functional connectivity (#3, 13 items), neurological indices (#4, 13 items), auditory modality (#5, 12 items), and influential elements (#6, 10 items).

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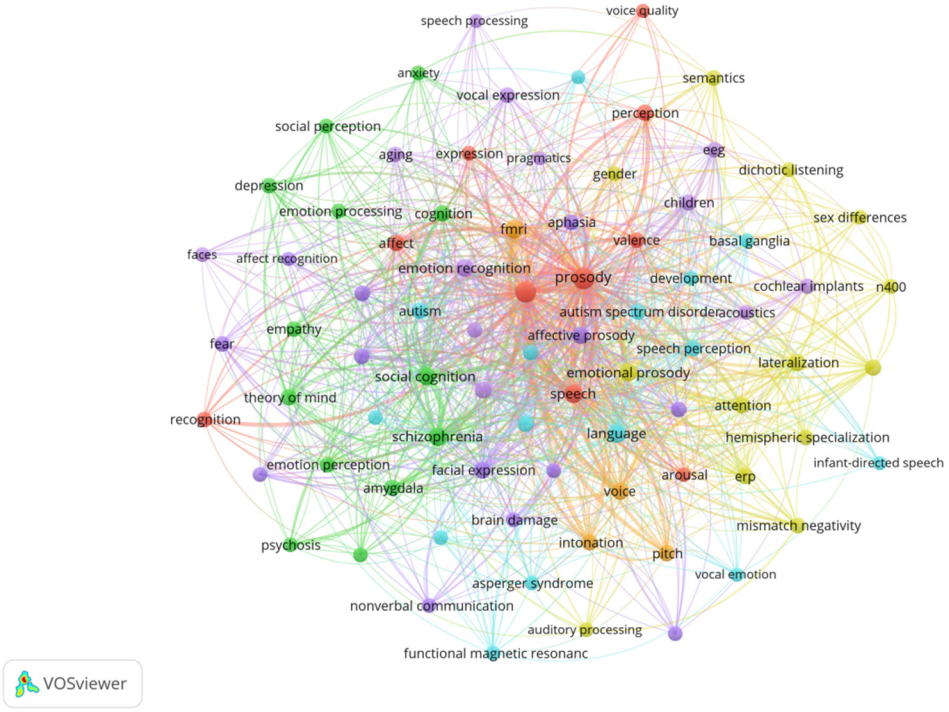

Figure 3. Map of indexed keywords that occurred at least 10 times in affective prosody publications.

With respect to the extraction and analysis of research themes, all four steps were strictly followed. The automatic extraction algorithm was introduced to extract 35,696 noun phrases in total. In the second step, a total of 248 noun phrases met the cut-off frequency and dispersion criteria, including 227 bigrams and 21 multigrams. Following the subjective labeling criteria, 110 noun phrases were labeled as possible research themes in the field of affective prosody, and all these recognized research themes were grouped into four categories (Supplementary Table S1). As several phrase groups were highly similar, cases that are substitutes for other group members due to lemmatization (e.g. emotion process/emotional processing/emotion process/emotional process) only kept the most frequently occurred noun phrase, while other pairs that are highly similar (or even synonyms) but irreplaceable were both kept (e.g. emotional content/emotional information). Last, the AR(1) autoregressive model was fit to define the hot and cold trends of selected themes, resulting in 19 hot themes and four cold themes (Table 5).

Table 5. Hot and cold research themes.

Research theme clusters	Frequency	Dispersion	AR(1) coefficient	*p*
cochlear implant (CI)	27	27	0.7313	0.0000
affective prosody	194	142	0.6428	0.0009
right hemisphere	175	139	0.6242	0.0005
emotion recognition	400	218	0.5738	0.0005
social cognition	99	71	0.5663	0.0022
prosody perception	41	41	0.5419	0.0016
angry prosody	35	35	0.5239	0.0019
autism spectrum disorder	70	65	0.5188	0.0022
recognition accuracy	41	33	0.5087	0.0045
vocal emotion	153	131	0.5085	0.0033
emotional prosody processing	29	29	0.4898	0.0040
prosody processing	51	51	0.4830	0.0053
emotional speech	189	120	0.4714	0.0084

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the child	44	44	0.4479	0.0121
vocal emotion recognition	27	24	0.4456	0.0155
event-relate brain potential	21	21	0.4382	0.0133
emotional face	44	44	0.3746	0.0413
basic emotion	70	67	0.3697	0.0499
superior temporal sulcus	24	24	0.3671	0.0473
emotion perception	91	73	-0.3923	0.0358
functional magnetic resonance imaging	87	87	-0.4196	0.0261
speech prosody	112	112	-0.5088	0.0032
linguistic prosody	47	32	-0.6588	0.0322

4. Discussion

The present bibliometric study revealed an increasing trend of affective prosody research in multiple academic disciplines over the past 25 years. Research impact was illustrated by influential countries/regions, significant institutes, and publication venues as well as disciplinary contributions and influential articles. For another, research themes were analyzed to manifest the changes of academic concern in this field over time. In an aggregated way, two major findings concerning the geographical contribution and primary research themes were identified based on current results. With a combination of the statistical findings and literature analysis, the limitations of extant affective prosody-related research and several prospective research directions were also proposed.

4.1. Geographical contribution

A geographic comparison elucidates that four countries have been leading affective prosody research, including the U.S., Germany, England, and Canada, while four countries constitute the second leading team, including China, France, Netherlands, and Switzerland. According to the results of productive authors, countries/regions, and institutes, the prior four countries consistently ranked top four on lists, all of which were recorded as early as in 1997 or 1998. As for the second leading team, both Netherlands and Switzerland are among the top in three indices, whereas China and France, which have published relevant articles since 2003, seem to fall short of highly productive institutes. Institutions with the most publications about affective prosody in China and France are Peking University with 22 articles (Rank #25) and the Centre National de la Recherche Scientifique (CNRS) with 25 articles (Rank #20), respectively. The proportion of the articles published by "super powers" in the other six leading countries ranges from 21.42% in the U.S. to 59.61% in Switzerland, but it only accounts for 9.61% in China and 9.09% in France. As such, a multi-great academic distribution pattern has been established in these two countries. For example, 60 Chinese academic or research bodies have published at least one article about affective prosody, among which Peking University (22 author counts, 14 correspondences), Chinese Academy of Sciences (16, 7), University of Hong Kong (15, 3), Shenzhen University (14, 4), Shaanxi Normal University (10, 3), and Chinese University of Hong Kong (9, 5) can be regarded as representative institutes in China. Another influential element for institutional information is that the same researcher may shift between institutes as a student, research assistant, or professor, leading to a high author-oriented but a low institution-oriented publication count. For example, the Chinese researcher Xiaoming Jiang published his first batch of articles as a member of the McGill University, and has contributed to Tongji University and Shanghai International Studies University in China over recent years. In short, the front for affective prosody studies is still centralized to countries famous for neuropsychological research, and the mobility in the researcher community can result in different academic distribution patterns.

4.2. Primary research themes

The increasing trend of affective prosody publications over the past 25 years suggests that this topic has become an academic concern for more researchers. Three significant research themes were

identified by a keyword analysis and thematic discovery, including clinical implication, measurable index, and modality-specific issues. In addition, the hot or cold tendencies of topics in each theme were also analyzed by means of time series regression.

Clinical implication consists of the brain area, mental disorder or patient group, treatment, and prognosis that are relevant to affective prosody. In this cluster, four hot themes were found. Two of the hot themes refer to brain regions, i.e., the *right hemisphere* and *superior temporal sulcus*, while the others denote a mental disorder (*autism spectrum disorder*) and a clinical treatment (*cochlear implant*). The right hemisphere (RH) is widely acknowledged as underlying affective prosody processing, whose damage can lead to a series of moderate to severe breakdowns in affective prosody expression (expressive aprosodia) and recognition (receptive aprosodia). Prior experiments that used emotional prosodic cues in a dichotic listening paradigm observed a right-hemisphere privilege (Ocklenburg et al., 2016; Thompson, 1995). Recent studies tried to apply explicit prosody training to patients with RH damage and to identify specific damage areas that can predict training effectiveness (Durfee, Sheppard, Meier et al., 2021). Superior temporal sulcus (STS), as part of the multi-sensory cerebral regions with an observable proportion of bimodal neurons (Watson et al., 2014), modulates audiovisual emotion integration. A recent study reported an enhanced activation of STS while processing the angry emotion in the visual modality (Zhang et al., 2018). Besides these two brain areas, other regions such as the amygdala, anterior cingulate cortex, and angular gyrus are also frequently investigated in affective prosody research. As for patient groups, several populations were identified as key research concerns, including schizophrenia and Parkinson's disease, or emerging targets like bipolar disorder (frequency: 25, dispersion: 21), whose functional and neurological responses to affective prosody can be noticeably impaired. Autism, as a neurodevelopmental disorder characterized by changes in affective prosody identification ability (Icht et al., 2021), has earned attention from a significantly increasing amount of research over the past decade, and affective prosody-related functional problems (Song et al., 2020) and clinical intervention approaches (Duville et al., 2021; Leung et al., 2021) have been examined in this population. Another aspect covered by clinical implications pertains to the hearing-aid apparatus. Experiments exploring the effect of cochlear implant (CI) on affective prosody perception firstly occurred in 2009 (Hopyan-Misakyan et al., 2009), and have ever since made much progress (see Everhardt et al., 2020, for a review) with extended scopes, such as tonal language (Ren et al., 2022), perceptive channel interaction (Richter & Chatterjee, 2021), and acoustic features in affective prosody production (Chatterjee et al., 2019).

Measurable index denotes an extensive range of peripheral elements of affective prosody that evaluate cognitive functions or modulate experiment settings. According to a leading model of affective prosody recognition (Sheppard et al., 2021; Wright et al., 2018), a three-stage device transforms affective prosody features into mental emotion representation, namely acoustic decoding and extraction (Stage 1), abstract emotion representation mapping (Stage 2), and semantic access (Stage 3). Domain-general cognitive processes, such as *social cognition* and *executive function*, interact with and mediate affective prosody processing between Stage 2 and Stage 3. As a result, these peripheral but essential activities have aroused significantly increasing attention in affective prosody research. Two neuroimaging methods showcased opposite trends. *Event-related potential (ERP)* has attracted increasing attention over the examined time span, while *functional magnetic resonance imaging (fMRI)* exhibited a significantly decreasing frequency. Although both methods show significance in psycholinguistic experiments, ERP has shown certain advantages compared to fMRI. First, fMRI can identify the spatially overlapping brain regions (fMRI) in affective prosody processing, but it can less accurately demonstrate the identical functions of identified areas and seems difficult to track time-dependent brain activities in the whole span of prosody processing (van Heuven & Dijkstra, 2010). ERP has a satisfactory temporal sensitivity and can conveniently map the potential dynamics to every involved cognitive activity, such as auditory perception, acoustic cue extraction, semantic representation and emotion judgement. Second, as fMRI is normally accompanied with ambient noise, such as gradient switching, radiofrequency pulses, and helium pumps, its application in auditory neuroscience is challenging and demands extra noise-controlling operations (Peelle,

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2014). Last, ERP is affordable and conveniently wearable in comparison with the expensive and cumbersome fMRI, though in the price of imaging fineness and accuracy (Zanzotto & Croce, 2010). Therefore, ERP has been increasingly employed in affective prosody studies by more academic bodies over time.

Themes related to modality-specific issues mainly cover the production and perception of speech (e.g. *speech signal*) and facial emotion (e.g. *facial emotion recognition*) in two modalities, including influential elements for affective prosody presentation (e.g. *acoustic feature*, *speech signal*). Although the collocation of *speech prosody* has decreased, subtler topics concerning speech have become popular recently. As audiovisual studies that contain affective prosody are still springing up, the theme *emotional face* is identified as a hot theme.

The hot/increasing and cold/decreasing trends for these research themes enlighten changes in research characteristics. Two inclinations are identified. One is the tendency transferred from speech in general to more specified emotional aspects, and the other denotes the extended scope in cognitive functions, neuroimaging approaches, and multidisciplinary collaborations. Firstly, recent studies are inclined to specify the brain-emotion-prosody connections in a more distinguishable and categorical way so that emotions and anatomical brain areas can be studied more profoundly. It has been found that cold themes such as *speech prosody* and *linguistic prosody* are too comprehensive for particular dysfunction investigation, and topics with narrower scope have been increasingly studied, such as *negative emotion* and *angry prosody*. The Emotion-type Hypothesis (Ross, 2021) also emphasizes that brain lateralization depends on a specific emotion type, which partially contrasts the prevailing Right Hemisphere Hypothesis and Valence Hypothesis. Secondly, the scope coverage has been extended. For studies that are highly relevant to affective prosody, many more linguistic and cognitive functions have been attended to, such as sarcasm, attention, memory, motivation, and cognitive control. Moreover, beyond ERP, fMRI, magnetic resonance imaging (MRI), and event-related electroencephalogram (EEG), other neuroimaging methods, such as near-infrared spectroscopy and diffusion tensor imaging, have also been incorporated to image brain activities. Besides, the urge for multidisciplinary collaboration also represents the extending scope. For instance, progress in Psychology, Neuroscience, and Linguistics increased our understanding about bodily functional connectivity with affective prosody, while advancements in Computer Sciences and Engineering strengthened the value in real-life scenes (Meftah et al., 2021).

4.3. Research limitations

With an inspection of the literature, we summarized two limitations of extant research, which mainly concern with individual differences and experiment-related influential factors. These two major limitations also contain the three identified primary research themes.

First, divergence of affective prosody ability caused by individual differences has been scantly investigated. This contains a set of factors, such as demographic backgrounds and sociocultural beliefs, and also includes the psycho-therapeutic interventions among patients with mental disorders. In the former concern, for instance, it has been suggested that the recognition accuracy of affective prosody decreases in the elderly (Demenescu et al., 2015), but such an aging effect was not acknowledged in clinical patients (Tang et al., 2022; Zhang et al., 2022). As most research only included similarly aged participants, especially in patients-oriented studies, this factor has been under-investigated. Similarly, other demographic and sociocultural elements, such as gender, education, intelligence quotient, language exposure and region, also require more in-depth investigations. Due to the limited statistics, the effects of these factors cannot be sufficiently aggregated even in relevant meta-analyses. On the other hand, as the research scope in this field has largely turned to patients with psychological disorders, the function of less reported clinical interventions, community psychological supports, and medications also remains questionable. It is likely that previous studies have mixed patients with and without external training for social communication enhancement. Moreover, recent studies also debated the effect of comorbidity, such as the alexithymia (Goerlich-Dobre et al., 2014) and hallucination (Larøi et al., 2019), in affect comprehension, so stronger evidence is urgently needed in the affective prosody research field.

Second, details of experiment rationales and statistics manipulation, such as stimuli preparation, task demand, and factorial analyses, also need to be carefully evaluated and correspondingly refined to address meaningful and latest topics in this field. Experiment rationales are concerned with the uni-modal and cross-modal designs, in which the affective prosody interacts with auditory messages and information delivered from other perception modalities, respectively. Statistics manipulation mainly refers to the subgroup analysis and multi-variate regression.

In the uni-modal condition, affective prosody, which is normally perceived from the auditory domain, can independently express the complete affect information or supplement other auditory cues (e.g., semantics) for affect comprehension. Hence, the discrepancy in task demands of uni-sensory perception (with non-verbal stimuli) and multi-sensory (with verbal stimuli) requires extra attention, and the presupposed cognitive demands should appropriately reveal the real capability without laying too much cognitive burden or reaching the ceiling effect. Although the core emotion-related functional system remains the same for the comprehension of affective prosody carried by verbal and non-verbal contents, the cognitive demands are different in that verbal stimuli involve both prosody interpretation and lexical retrieval. In fact, with the imposition of verbal contents, brain regions for linguistic prosody, such as the middle frontal gyrus, are activated in addition to those for affective prosody processing, and the mutual interaction has not been completely illustrated (Belyk & Brown, 2014). Besides the uncertainty caused by material contents, the presentation duration of experiment stimuli also matters in the uni-modality conditions. Although affective prosody needs to be carried by temporally longer auditory pieces, listeners can identify the vocal emotion within an immediate exposure (100 ms), and the identification accuracy of vocal emotion will increase with longer exposure duration if beyond this threshold (Nordström & Laukka, 2019). As indicated by a recent meta-analysis (Leung et al., 2022), extant affective prosody perception experiments among autism patients mostly restricted the presentation time to around 300-3000 ms, which has already exceeded the need for affective prosody identification. As a result, other compensatory strategies for prosody judgement could hardly be eliminated, thus leading to highly heterogeneous findings. In short, divergent findings in the uni-modal conditions of affective prosody research have been reported due to different material types and presentation duration, and the effects of these experiment-related factors need to be further clarified.

In real life, affect is usually conveyed through different modalities (e.g., visual, auditory) and channels (e.g., facial expression, gestures, speech prosody, semantics), and affect-related research, as mentioned above, has shown an increasing trend for multi-modal comprehension. The scope of cross-modality affect research undoubtedly enhances the practical and academic values of relevant findings, but also perplexes the experiment design at the same time. In the cross-modal conditions, previous research mostly explored the interaction between affective voices and emotional facial expressions, and difficulties involved in task design include the perception channels (e.g., face, mouth, voice), facial expression presentation (e.g., static, dynamic), examined condition (e.g., congruence, incongruence), and emotional dimensions (e.g., valence, arousal). It has been suggested that at least two independent cognitive processes participate in the cross-modal affect comprehension, including cross-modal prediction and audiovisual integration (Jessen & Kotz, 2015), with the former normally investigated in the priming paradigm and the latter Stroop paradigm. However, existing evidence has not yet reached convincing conclusions on either the consecutive affect prediction or simultaneous integration. For example, the results of the topics, such as the time points at which congruent auditory and visual messages are integrated and whether mouth movements can sufficiently influence the perception of contradictory vocal affects, are still inconsistent and urge further sophisticated exploration. Besides, stimuli types may also alter the behavioral and neurological observations, and dynamic facial expressions (Garrido-Vásquez et al., 2018), as a more ecologically valid counterpart to the dynamic affective prosody in speech, have been scantly investigated compared to the static facial expressions.

The last experiment-related factor refers to statistical analysis, and emerging experiments should pay more attention to refining the analytical methods and factorial coverage. In patient-oriented research, the impairment of affective prosody recognition may only exist in certain emotion types,

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which also vary as a function of the psychological disorders. Under such a circumstance, a subgroup analysis for emotion type is conducive to providing valuable details. Moreover, more sophisticated factorial analyses and meta-regression need to be carried out in individual experiments, especially in studies involving clinical patients. For instance, the effects of task types (e.g., discrimination, identification, labeling), symptom measures (e.g., Beck Depression Inventory, Montgomery-Asberg Depression Rating Scale), and illness episodes (e.g., manic, depressive, borderline, euthymic, remitted) need to be clearly illustrated with appropriate enrollment criteria and analytical approaches.

4.4. Future directions

Enlightened by the statistical findings of the present bibliometrics-based analyses, two promising future directions are proposed for emerging affective prosody research. Vertically, the location of activated brain regions and the neural networks of affective prosody processing need to be more systematically identified, and a series of neural activities temporally involved in the top-down and bottom-up mechanisms of affective prosody comprehension remain to be specified and integrated. Horizontally, the scope of research in this field is suggested to be extended from the sociocultural and practical aspects.

Neuropsychological studies are primarily important in the field of affective prosody, as the findings can associate cognitive and behavioral responses with neural activation to understand human activities in a more systematic and profound way. Hence, the spatial location and temporal development are equally important. As one of the ultimate objectives for human speech understanding, the complete neural networks for prosody production and perception are of great significance at the psychology-neurology-linguistics interface. From a macroscopic perspective, as affective prosody and linguistic prosody are usually perceived in parallel in the auditory domain of speech stream, and affective prosody usually occurs in accompany with cross-modal cues (e.g., facial expression , gestures) in real life, researchers need to continue deepening our understandings of multi-modal and multi-sensory affective prosody production and perception. Furthermore, since speech production and perception together constitute human speech communication, more endeavors should also be made to construct a complete system for speech, which incorporates extant neural models of speech prosody perception with those of production. From a microscopic approach, neuropsychological mechanisms for different prosody types also need to be discriminated and isolated, and functional-anatomic subdivisions are clinically meaningful for the screening and prognosis of patients with different prosody impairments. With respect to the temporal features of prosody comprehension, three stages were suggested to occur in this procedure, including the sensory processing, affective cue integration, and evaluative judgement (Schirmer & Kotz, 2006). Different brain regions were found activated in each stage, such as the auditory cortex, lateral superior temporal cortex, and the superior temporal sulcus (Belyk & Brown, 2014; Wildgruber et al., 2006). However, these previously reported regions may be shared or isolated with various experiment tasks that adopted different stimuli. For instance, a comparison between simple and complex emotions identified some commonly activated areas, such as the temporal and lateral frontal brain regions, but complex emotion additionally involved the medial prefrontal cortex, frontal operculum and left insula (Mitchell & Ross, 2013). Similarly, the processing mechanisms are also suggested potentially different as a function of prosody types, such as the emotional prosody and attitudinal prosody, especially in the inferior frontal, orbitofrontal, and limbic regions (Mitchell & Ross, 2013). Therefore, the interaction between prosody comprehension stages and different experiment stimuli urges further investigation.

On the other hand, the scope of affective prosody research needs to be broadened. Discrepancy caused by different sociocultural and language backgrounds is of great interest in the psycholinguistic discipline, and straightforward comparisons in large-scale cohort or multi-center experiments are needed to trace the longitudinal and cross-sectional variations of affective prosody ability. For example, tonal language speakers use pitch information (fundamental frequency) for semantic interpretation, so they rely more on other prosodic cues, such as duration and intensity, to identify affective prosody (Wang & Lee, 2015). As such, observable differences may exist in both

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production and perception of affective prosody among tonal and non-tonal language users. In addition to the academic scope, affective prosody is showing its presence in the computer science and engineering fields, and has been tentatively used as an intervention approach for life quality improvement (Duville et al., 2021; Lee, 2021). In the future, researchers need to deepen the connection between academic findings and industrial applications.

Last, to support the general development direction for affective prosody research, we further examined the characteristics of recently most cited publications. Highly cited articles published before 2010 mostly reported the general neurological mechanisms (Borod et al., 1998; Morris et al., 1999) and processing deficits caused by mental disorders (Edwards et al., 2001) in an independently separate way. Ever since 2010, important research in this field mostly embraces an integrative and innovative nature. A bunch of most influential studies has recently reached out to compare neuropsychological responses and functional activities concerning affective prosody in different populations, which can reveal influential factors for affective prosody processing, such as demographic age (Piazza et al., 2020) and culture (Laukka & Elfenbein, 2020). For another, the creativity usually lies in insightful comments and refinements for enriching existing findings based on comprehensive knowledge in particular disciplines. For example, Grandjean (2021) proposed an integrated model consisting of five main systems for affective prosody processing, which serves to invoke essential functions of affective prosody in social interactions. In the area of computer science and engineering, El Ayadi et al. (2011) provided thoughtful suggestions for improving current emotion categorization systems and databases after examining their characteristics and techniques. In summary, the general direction for integration and innovation warrants the proposed future directions of systematically profound neurological illustration and enlarged research scope.

5. Conclusions

In this study, we examined the research development in the field of affective prosody over the past 25 years by exploring research impact and diachronic trends, which generated two major findings. First, the front for affective prosody studies is located in the U.S., Germany, England, and Canada, while China, France, Netherlands, and Switzerland are also emerging as significantly leading countries. Additionally, different academic distribution patterns may result from mobility in the researcher community. Second, clinical implication, measurable index, and modality-specific issues are three popular themes about affective prosody. With the combination of statistical results and a qualitative literature inspection, limitations of extant studies and promising research directions in this field were proposed. In specific, limitations mainly denote the individual variations and experiment-related influential factors. As for future directions, research in this field is heading towards a systematically in-depth direction for neurological networks at the content level and an extensive and multidisciplinary perspective for scope, and the most cited publications in the past ten years emphasized more on integration and innovation.

Although the present study has obtained informative findings about affective prosody research, two limitations should be notified clearly. First, article retrieval and data extraction can be refined. The current study compromises between the recall ratio and precision ratio by employing a relatively loose query method (Chen, 2017), which accesses as many affective prosody-related journal articles. However, there still remains a small proportion of relevant articles that do not use the query terms in the title and abstract, which may lead to incompleteness. Additionally, articles pertaining to affective prosody or speech prosody may also exist in other databases, such as Ei Compendex and Scopus, which help paint a fuller picture of affective prosody research. Second, results of the present need to be explained with caution, especially the negative ones. For example, the identified cold themes are not necessarily neglected by researchers, which can be interpreted with a few feasible reasons, such as the change of terminology and the narrowing of research focus.

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