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Characterizing scientific elites: publication and citation patterns of outstanding scientists in biomedicine

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ABSTRACT

Science is principally driven by the efforts of a small fraction of researchers publishing the majority of scientific research and garnering the majority of citations. The quantitative analysis of outstanding scientists' publication and citation patterns provides a new perspective for understanding of scientific talents. The study of outstanding scientists can enhance our understanding of the publication and citation patterns and their scientific careers more generally. Based on 35,315 research papers from the biomedical field, we analyzed the academic productivity and influence characteristics of 244 outstanding scientists in biomedical field. Several interesting patterns are observed as follows: as outstanding scientists' career age increased, (1) their scientific output shows a trend of decreasing after increasing, (2) their academic influence shows a trend of continuous growth, (3) their number of the co-authors in their scientific career first increases and then remains stable, and (4) the number of their research areas first decreases and then increases.

KEYWORDS

Outstanding scientists; Scientific career; Quantitative analysis; Academic productivity and influence

1 Introduction

IImportant scientific breakthroughs are inseparable from the support of policies, talents and enterprises, especially the accumulation and inheritance of scientific knowledge and academic thoughts (Ren et al., 2019). Scientific elites deserve our attention because their contributions and achievements have played an important role in the advancement of scientific knowledge (Zuckerman, 1977). Among these scientific and technological elites, outstanding scientists refer to those who had made great achievements in scientific research and have been recognized with major scientific honors (Li, 2009; Xu & Lin, 2014). With a broad interdisciplinary vision, outstanding scientists are invaluable to social development, so it is meaningful to study the development of their research careers. According to different theories of career development, many researchers had divided the careers of outstanding scientists into different stages (Fan et al., 2011; Hall, 2002; Wu, 2004; Guo, 2007; Luo et al., 2012; Liao, 2004). Career research on scientists can be traced back to the beginning of the 20th century (Parsons, 1909). The career development patterns and influences of researchers have been a hot topic of research, mostly focusing on Nobel Prize winners or outstanding scientists in

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various fields. Lehman (2017) found the peak age of scientific creativity for the first time. Jones (2010) made a regression analysis of 547 Nobel Prize winners and 286 great technological inventors from 1901 to 2003, and found that the mean age at which they produced great achievements rose by about six years. Xia (2001) studied the scientific research data of 116 Nobel Prize winners in Physics from 1901 to 1980, and found that the optimal biological age for outstanding scientists to conduct scientific research is 28-40 years old.

Outstanding scientists are invaluable to the development of society and are scarce human resources (Li et al., 2008). These evaluation indicators (i.e., academic age) of academic influence are closely related to the length of a scientist's academic career. Falagas, Ierodiakonou and Alexiou (2008) evaluated the best age for biomedical scientists to make significant contributions and found that scientific output decreased as academic age increased. Jones and Weinberg (2011) found that the frequency of researchers' high achievements when they were young was related to time, and has nothing to do with the field. Egghe (2013) improved the H-index of scientific researchers and introduced the occupational age factor into the evaluation model. Previous researches have studied the age or time factors which affected outstanding scientists' academic productivity and influence, but there still exists big room to explore the evolution of outstanding scientists' academic contributions over time. By analyzing the publishing practice of outstanding scientists in biomedical research field, this paper focus on the dynamic changes of scientific publication characteristics at different times during their scientific career.

In order to explore the publishing patterns of outstanding scientists, we use bibliometrics methods to quantitatively analyse the evolution of publications, citations, scientific cooperation and research interests of outstanding scientists at different career stages. This study contributes to a more detailed and systematic understanding of the publication characteristics of outstanding scientists by examining their research behaviours at different career ages. In sum, we expect that the results can provide an empirical basis for a deeper understanding of the publication characteristics of outstanding scientists in science.

2 Related Work

In order to examine publication characteristics of outstanding scientists, the current study focuses on three types outstanding scientists according to their academic seniority. The research on the evolution rules of outstanding scientists' academic influence is the frontier of sociology of science (Xu et al., 2016). In previous studies, scholars usually define outstanding scientists according to the following criteria. Criteria 1: scientists who have won top international scientific awards in a certain field (Gao et al., 2016). Criteria 2: In addition to obtaining academic degrees through academic experience, scientists also have special academic status, such as academicians from various countries and research fields (Xu et al., 2016). Criteria 3: Scientists are cited at a very high level, though they may not have received top international science and technology awards (Du et al., 2011). Criteria 4: Scientists have a very high H index.

There are different kinds of databases of scientists in the world, such as ISI Highly Cited Scientists, Members of National Academies of Science, Nobel Prize winners, etc. The Global Scientist Database by John P.A. Ioannidis team was published on the open-source database website[1] in August 2019, as shown in figure 1 (Ioannidis et al., 2019). In this paper, the out-

1 https://data.mendeley.com/datasets/btchxktzyw/1.

standing scientists in the database are taken as our research samples in biomedical research field.

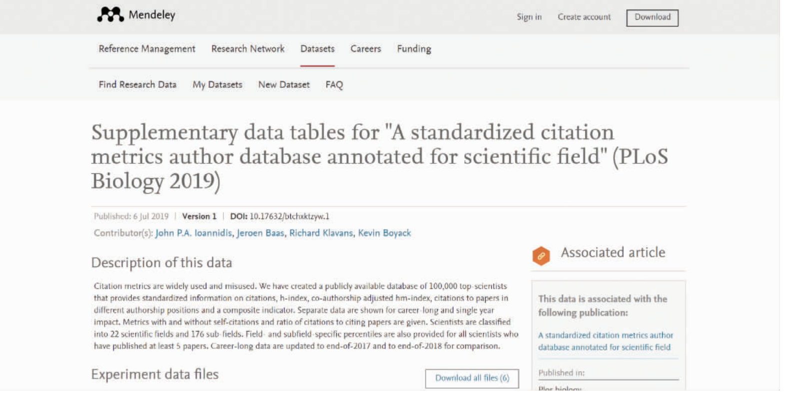

Figure 1 Website of the Global Scientists Database

The data in the Global Scientists Database are sourced from the Scopus database. The ranking order of scientists is calculated by combining the values of several indicators, including the total number of citations from 1996 to 2018, Hirsch h-index, coauthorship-adjusted Schreiber hm-index, number of citations to papers as single author, number of citations to papers as single or first author, and number of citations to papers as single, first, or last author. The comprehensive score C was calculated according to the formula (1) proposed by John P.A. Ioannidis, and sorted according to the comprehensive score C in the database.

$$c = \frac{\ln(nc9618+1)}{\ln(nc9618max+1)} + \frac{\ln(h18+1)}{\ln(h18max+1)} + \frac{\ln(hm18+1)}{\ln(hm18max+1)} + \frac{\ln(ncs+1)}{\ln(ncsmax+1)} + \frac{\ln(ncsf+1)}{\ln(ncsfmax+1)} + \frac{\ln(ncsfl+1)}{\ln(ncsflmax+1)} \quad (1)$$

where *nc*9618 is the total number of citations from 1996-2018, *h*18 is the h index up to 2018, *hm*18 is the hm index up to 2018, *ncs* is the number of citations to papers as a single author, *ncsf* is the number of citations to papers as single or first author, and *ncsfl* is the number of citations to papers as single, first, or last author. The *nc*9618*max* is the maximum value of *nc*9618. The *h18max* is the maximum value of *h*18. The *hm18max* is the maximum value of *hm*18. The *ncsmax* is the maximum value of *ncs*. The *ncsfmax* is the maximum value of *ncsf*. The *ncsflmax* is the maximum value of *ncsfl*.

The indicators in the Global Scientist Database related to scientists' research areas are: top ranked higher-level Science-Metrix category(out of 22) for author, first ranked Science-Metrix category (out of 176) for author, second ranked Science-Metrix category (out of 176) for author. The biomedical research field studied in this paper is selected from the discipline categories with the highest proportion of scientists' papers.

There are 20 research fields in the Global Scientist Database, covering a wide range of disciplines and research fields. Biomedical research is the hotspot and frontier of life science research in this century. Many countries, such as the United States and Germany, have also launched the National Bio-economic Blueprint and National Research Strategy: Bio-economy 2030, etc. It is mentioned in the regulations of China's "13th Five-Year Plan for Bio-industry

Development" that advanced university biotechnology should be developed, and biotechnology innovation should drive innovative development such as life and health and bio-manufacturing (Ministry of Science and Technology, 2017). In the current bibliometric research on outstanding scientists and their publications, Kademani et al. (1999) analyzed the number of articles published by Dorothy Mary Crowfoot, winner of Nobel Prize in Chemistry in 1964, in core journals every five years and confirmed that it conformed to Bradford-Zipf's law. Zhou et al. (2014) made a bibliometric analysis of 382 landmark papers of 193 Nobel Prize winners in Physics from 1901 to 2012, and obtained the characteristics and trends of citation times, journal influence factor and publication countries. Egghe et al. (2012) analyzed the positive correlation between the commonly used scientometrics index (H index) and the number of zero cited papers from the perspective of zero cited papers of Nobel Prize winners and Fields Prize winners. Most of the existing studies have taken Nobel Prize winners etc. as outstanding scientists to make related work, while few research have taken top biomedical scientists as research cases to explore their publication characteristics. Biomedical research, with its leading role in discipline construction and revolutionary influence on the development of human society and science, is currently at an exceptionally rapid development level. This field includes many closely related and completely different research directions, such as biochemistry and molecular biology, genetics and immunology, etc. At the same time, new research directions are constantly emerging in this field, and some of them are on the verge of major breakthroughs. In view of these considerations, this paper selects distinguished scientists in the field of biomedical research as our research object for this study.

3 Methodology

3.1 Data and Sample

The dataset used in this study is derived from "A standardized citation metrics author database annotated for scientific field" (Ioannidis et al., 2019), which includes 100,000 top scientists' standardized information. Scientists are classified into 22 scientific fields and 176 subfields. In this article, we conduct research on outstanding scientists in the field of biomedicine.

The following is an introduction to the data process of selecting outstanding biomedical scientists. The samples were selected outstanding scientists:

$$m \approx 0.749\sqrt{n_{max}} \quad (2)$$

$$R \approx \frac{0.812}{\sqrt{n_{max}}} \quad (3)$$

Where *m* is the minimum number of papers for outstanding scientists. n_{max} is the maximum number of papers published by scientists. R is the ratio of the number of outstanding scientists to the total number of scientists.

First, formula (2) was used to screen the scientists in the biomedical field from three perspectives: the maximum number of papers, the maximum number of citations (including self-citations), and the maximum number of citations (excluding self-citations). A total of 13,326 scientists were found to meet the conditions. Since the sample size was still too large, formula (3) was then used to determine the number of research samples. Finally, the top 244 scientists in the biomedical field were selected as the research samples. By searching for the authors' names, we downloaded all the papers of the scientists in the Web of Science as of

December 31, 2019. After data cleaning, we finally collected 35,315 papers of these outstanding scientists in the biomedical field.

3.2 Data Classification

The career age of a scientist was defined as the year of the scientist's last published paper minus the year of the scientist's first published paper. Through statistics, we observed that the career age of outstanding biomedical scientists is mainly 20-50 years. Therefore, we divided outstanding scientists into three groups: those with a career of 21-30 years are defined as low seniority scientists, those with a career of 31-40 years are defined as medium seniority scientists, and those with a career of 41-50 years are defined as high seniority scientists.

3.3 Indicator Selection

In order to explore the publication and citation patterns of outstanding scientists, this paper used 9 indicators.

(1) The number of single-author papers: The total number of single-author papers published by an outstanding scientist over a period of time.

(2) The number of co-authors papers: The total number of co-authors papers published by an outstanding scientist over a period of time.

(3) The ratio of co-authors papers to single-author papers: The ratio of the number of co-authors papers divided by the number of single-author papers in the career of an outstanding scientist.

(4) The total number of papers: The total number of papers published by an outstanding scientist over a period of time.

(5) The total number of citations: The total number of citations of papers published by an outstanding scientist over a period of time.

(6) The average number of citations: The ratio of the total number of citations of an outstanding scientist divided by the total number of papers.

(7) The number of co-authors: The total number of papers with multiple authors published by an outstanding scientist over a period of time.

(8) The number of papers in different subdivision areas: The number of papers published in each field during outstanding scientists' careers is added up separately.

(9) The dominance co-efficiency of the author's signature sequence (DC for short). Among these indicators, we adopted the indicator DC and DI (dominance index of a scientist or an author) proposed by Peidu (2019) to distinguish the contributions of the different authors in one paper:

$$\mathrm{DI} = \frac{B-A}{A+B} \quad (4)$$

$$\mathrm{DC} = \frac{B-A}{A+B}\mathrm{M} \quad (5)$$

Where A is the sum of times of co-authors ranked above the author in the by-line of all the co-authors papers, B is the sum of times of co-authors ranked below the author in the by-line of all the co-author papers. M is the total number of multi-author papers. Formula (4) shows that DI is a measure of an author's standing or prominence among his or her co-authors based on the ranking or position in the ascription of all the co-authors papers. When DI = 1, it is absolute dominance: author has been first author in all the papers. DI = 0, neutral dominance. DI =-1, it is absolute subservience: author has been last author in all the papers. Formula (5) shows that DC is the product of paper of significance and DI. DC measures the contribution of authors when they are in a dominant or dominant position in the publication of collaborative papers. A higher DC for a distinguished scientist indicates that he or she contributed more than other co-authors in conducting research and writing papers in his or her co-authored publications (Peidu, 2019).

4 Results

This paper analyzed the publication and citation patterns of 244 outstanding biomedical scientists. According to the division of seniority, 73 scientists belong to low seniority researchers, 100 scientists belong to medium seniority researchers, and 71 scientists belong to high seniority researchers. To observe the correlation between different indicators, we calculated the correlation coefficients between different indicators using statistical methods. Among the 9 indicators selected in this paper, several indicators had significant correlation, and the changes of indicators had a strong consistency. Therefore we selected 6 indicators of scientists for correlation analysis, including the total number of papers, the average number of citations, the total number of co-authors papers, DC and the average number of co-authors. Table 1 shows the Spearman correlation coefficients among the 6 indicators of 244 scientists.

Table 1 Correlations of scientific research indicators

	total number of papers	average number of citations	total number of co–authors	total number of citations	DC	average number of co–authors
total number of papers	1					
average number of citations	–0.092	1				
total number of co–authors papers	.992**	–0.072	1			
total number of citations	.669**	.619**	.683**	1		
DC	.212**	–.330**	.181**	–0.106	1	
the average number of co–authors	.269**	.163*	.301**	.343**	–.614**	1

Note: ** The correlation is significant at the 0.01 level (two–tailed).
* The correlation is significant at the 0.05 level (two–tailed).

Table 1 shows that the total number of papers has a positive correlation with the DC, the total number of citations, the total number of co-authors papers and the average number of co-authors. There is a negative correlation between the average number of co-authors and DC. To examine the characteristics of outstanding scientists at different career stages, we analyzed publication and citation patterns of three types of outstanding scientists with different seniorities.

4.1 Analysis of the scientific output

First, we analyzed how the productivity of each outstanding scientist evolved in over career stages and explored the overall relationship between career age and publication rates. Table 2 shows the average and median number of papers published by scientists at different stages. Figures 2 shows the total number of papers and the weighted mean of each career stage for each outstanding biomedical scientist with low, medium and high seniority.

Table 2 The average and median number of papers by scientists at different stages

		Career age/years					
		1–10	11–20	21–30	31–40	41–50	M
Low seniority	Mean	21.81	50.75	48.40			40.32
	Median	19	41	31			
	n	73.00					
Medium seniority	Mean	15.54	35.90	48.81	32.72		33.24
	Median	13	31.5	41	21		
	n	100.00					
High seniority	Mean	17.32	30.61	48.97	43.34	23.85	32.82
	Median	12	24	42	35	13	
	n	71.00					
Overall	Weighted mean	17.93	38.80	48.73	37.13	23.90	

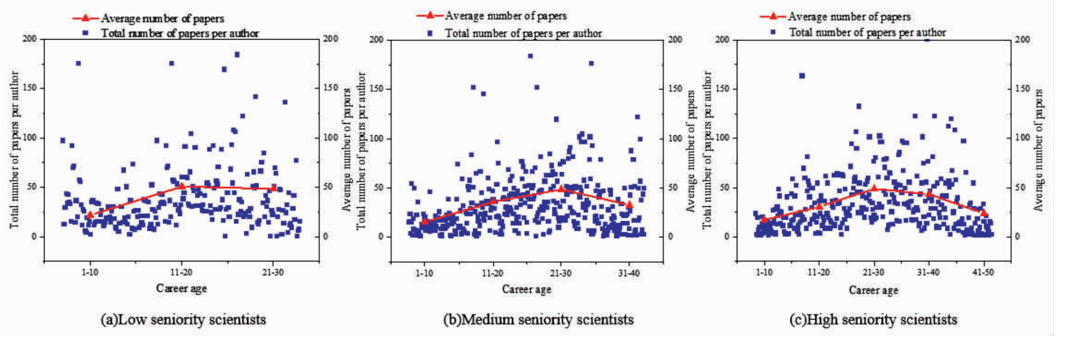

Figure 2 Statistics on the number of papers published by scientists at different stages

The results show that the average number of papers published by low seniority scientists reaches its peak in career years 11-20, it declined in career years 21-30, but remains at a high level of output, and the average number of papers published by both high and medium seniority scientists make the highest output in career years 21-30. According to the overall weighted means, the average number of papers in career years 1-10 was 17.93, rapidly increased to 38.80, rose to a peak of 48.73 in career years 21-30, and then decreased to 37.13 in career years 31-40 and to 23.90 in career years 41-50. There is an obvious trend of increase in the number of papers published by medium and high outstanding scientists in their career years of 1-30 years, and it falls down significantly after their career years of 31 years, which is far lower than that in the initial stage of scientific research (11-20 years).

In addition, the average number of papers published by low seniority scientists is significantly higher than that of other scientists, while the average number of papers published by medium seniority scientists is slightly higher than that of high seniority scientists. This is because with the increased career age after the age of 30, the decline in publication drags down the average number of papers of medium and high seniority outstanding biomedical scientists.

Then, we analyzed the output of single-author and co-authors papers by scientists. Figure

3 shows the statistics on the number of single-author or co-authors papers by outstanding scientists at different levels of seniority. We observed that the output of single-author papers by three groups of scientists has been maintained at a relatively low level, while the number of co-authors papers fluctuated. According to the ratio of the number of co-authors papers to the number of single-author papers, with the increase of the career age of outstanding scientists, the willingness to publish in the way of co-authors papers has always become stronger.

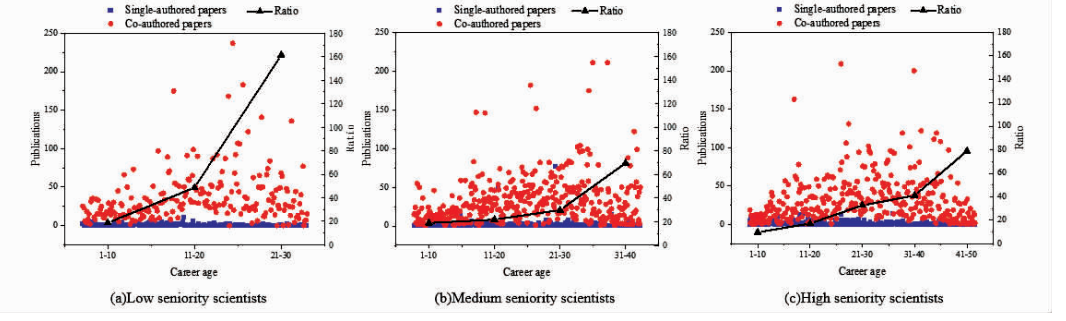

Figure 3 The ratio of co-authors to single-author papers by scientists at different stages

4.2 Analysis of the academic influence

Figure 4 shows the analysis result of the average number of citations and the total number of citations of outstanding scientists in different career stages.

Figure 4(a) shows that the total number of citations remains high with career age for the lower seniority scientists, with the highest total number of citations (4116.6 citations) during the 11-20 years of their career. The average number of citations remains high and tends to increase significantly with career age. Although the total number of citations has declined during the 21-30 years of their careers, this decline is mainly due to the reduction of the number of papers, and the influence of papers by outstanding scientists has been steadily increasing with career age.

Figure 4(b) shows that the total number of citations of medium seniority scientists increases and then decreases, with the highest total number of citations (4228.3 citations) during the 11-20 years of their careers. The average number of citations tends to increase significantly with career age. Although the total number of citations has tended to decline significantly during the 21-40 years of their careers, and even drops to an even lower level in the 31-40 years of their careers than at the beginning of their careers, the decline is mainly due to a decrease in the number of papers. The influence of the outstanding scientists' papers has been increasing steadily with their career age, and the increase has tended to increase gradually.

Figure 4(c) shows that the total number of citations of high seniority scientists increases with career age at the beginning of their careers, and then gradually decreases, with the highest total citations during their 21-30 years of careers (5007.2 citations). The average number of citations tends to increase significantly with career age. Although the total number of citations for outstanding scientists tends to decline significantly during the 31-50 years of their careers and drops to a level well below that of the beginning of their careers in 41-50 years, the average number of citations shows that, like those in 31-40 years of career, the decline is mainly due to a decrease in the number of papers. The impact of the outstanding scientists' papers has been steadily increasing with career age, and the trend of increasing citations has become more pronounced, indicating that the quality of scholarly output has increased significantly.

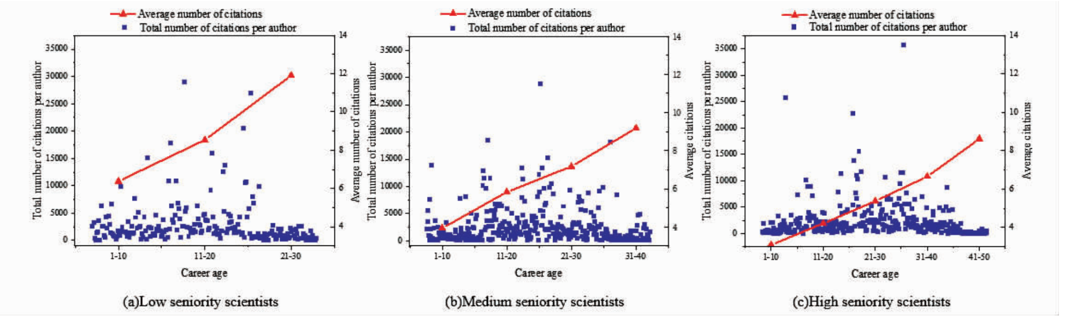

Figure 4 The average and the total number of citations by scientists at different stages

4.3 Analysis of the scientific research collaboration

By analyzing the number of co-authors papers published in career stages, Figure 5 shows that the average number of co-authors papers for the three groups of scientists has an obvious increasing trend, and the number of co-authors papers to the number of single-author papers published by each group of scientists reaches a peak during the 21-30, 31-40 and 41-50 years respectively. It shows that the willingness of outstanding scientists to publish as co-authors has been tending to become stronger as their careers age get longer, and their academic social relationships stabilize as their careers age.

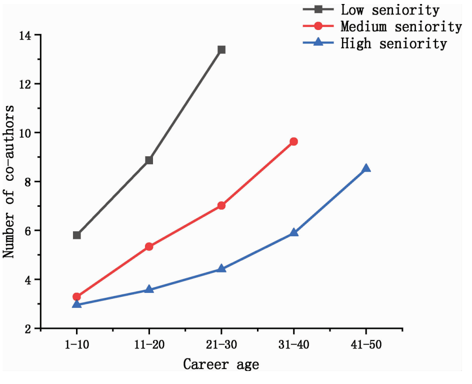

Figure 5 The number of co-authors papers by scientists at different stages

Subsequently, we analyzed the DC of scientists in different stages of their careers. Figure 6 shows the average DC of the three groups of scientists in the different career stages. The results show that the DC of the three groups of scientists has a significant downward trend, indicating that with the growth of career age, the academic cooperation of outstanding scientists develops rapidly, and in most cases; they carried out academic research and published papers as the non-first author of the team. Based on the results obtained in 4.1 and 4.2, during this process, the academic output efficiency of outstanding scientists has decreased, but the level of scientific research achievements gradually has increased, which indicates that the change of their status did not affect the continuous improvement of the influence of scientific research achievements.

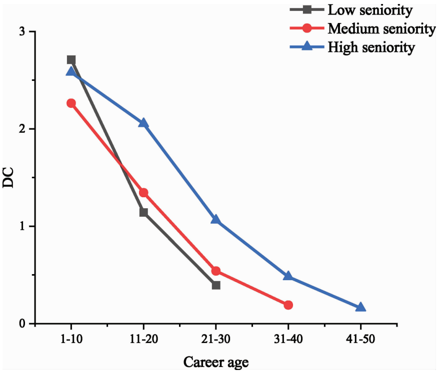

Figure 6 DC statistical results of scientists over career stages

4.4 Analysis of the evolution of scientists´ research interests

In this part, we analyzed the number of papers published by outstanding scientists in different research fields and concentrated on the top ten research interests. Since the papers are retrieved and downloaded from the Web of Science, the research areas of papers are categorized according to the classification of the Web of Science.

Figure 7 shows the change in the number of research directions of outstanding scientists with three different seniorities. The number of research directions decreases first and then increases. The number of papers per author increases first, after reach a certain peak and then slowly begin to decline as the career age increases.

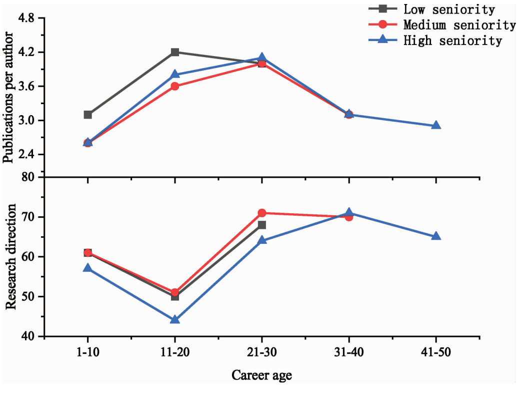

Figure 7 Changes in the number of research directions by scientists at different stages

The number of papers by outstanding scientists in different stages fluctuates with the increase of career age, and there is no consistent change rule. Figure 8 (a), (b) and (c) show the evolution statistics of the top ten research directions published by outstanding scientists with different seniorities. In particular, the research interests of outstanding scientists with low seniority can be easily changed. Epidemiology has been in a low state of research during the career of 1-10 years and 11-20 years. In 21-30 years, it has become the first of all research directions. Their research mainly focuses on biochemistry and molecular biology, critical care medicine and mycology. The research interests of medium seniority scientists in the fields of biochemistry, molecular biology and virology have been maintained at relatively stable levels. Compared with low seniority scientists, medium seniority scientists are able to consider all various research fields at the same time. In addition, the research fields can be returned to the original level in a short time after being reduced. Their research mainly focuses on nutrition, biochemistry, molecular biology and virology. Senior scientists have long been interested in some fields, and pay more attention on academic publications that are more relevant to their research fields, mainly in the fields of biochemistry and molecular biology, microbiology, virology and immunology.

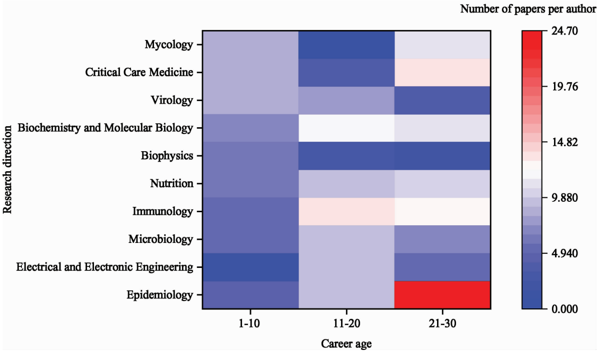

Figure 8 (a) The evolution of the research interests of low seniority scientists

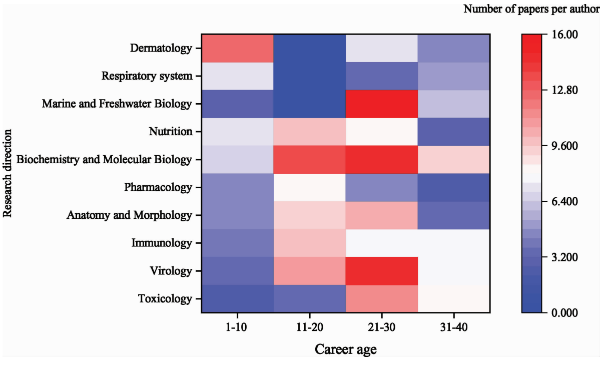

Figure 8 (b) The evolution of the research interests of medium seniority scientists

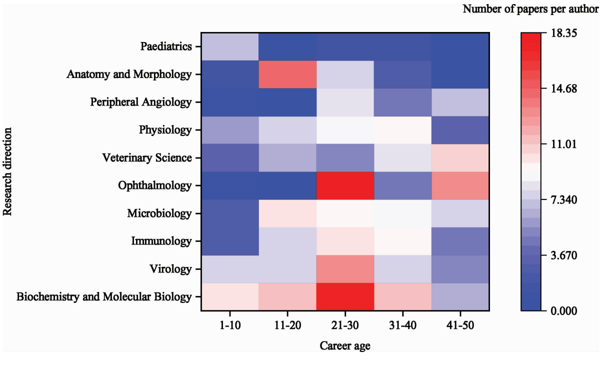

Figure 8 (c) The evolution of the research interests of high seniority scientists

5 Conclusion

This study examined the publishing practices of outstanding scientists in biomedical field, characterizing several publication patterns about outstanding scientists. We selected 244 outstanding biomedical scientists, collected 35,315 papers through the Web of Science and analyzed 9 indicators of publication and citation behavior. Many researchers had noted there exist changes in the productivity and scientific creativity of outstanding scientists over time (Falagas et al., 2008; Costas et al., 2010; Jones & Weinberg, 2011; Men & Zhang, 2013). Similarly, this paper found that the research output and academic influence of prominent scientists changes over time as career age increases. Finally, we summarized the regularity and found several publication characteristics: (1) The output of outstanding scientists increases and then decreases over their different career stages. Generally, the growth trend can only be maintained in the first 30 years during their career, and the peak value of publication is about 50 papers per decade. After 30 years, the number of papers will obviously decrease. (2) The influence of outstanding scientists' academic achievements continues to grow in their careers, which is reflected in the growth of the average number of citations per paper and its growth rate. (3) As career age increases, the number of outstanding scientists' collaborators first increases and then stabilizes. (4) In different career stages, the number of research areas of low, medium and high seniority scientists first decreases and then increases. The research interests of low seniority scientists mainly focus on biochemistry and molecular biology, critical care medicine and mycology. Medium seniority scientists mainly focus on nutrition, biochemistry and molecular biology and virology. High seniority scientists mainly focus on biochemistry and molecular biology, microbiology, virology and immunology.

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