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Discovering types of research performance of scientists with significant contributions

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Abstract

This study compared the longitudinal research performance of 50 biological scientists who received the National Medal of Science (NMS) between 1995 and 2014 and who shared the honor of receiving a fellowship from the American Academy of Arts and Sciences. Fifty NMS scientists were categorized based on their annual number of publications (research productivity) and their annual average number of citations received per publication (research influence). These categories covered all their articles, conference papers, and review articles before 2018 indexed by databases of Web of Science, divided into three periods. Results demonstrated that the primary type of research productivity was the same as that of research influence, indicating an upward trend in the first period but a decreasing trend in the second and third periods. Few scientists had their influential scientific contributions being practically applied and presented in the format of a book. Research performance among 50 NMS scientists varied at the individual level. However, no aggregate and statistically significant differences were identified between groups of 50 NMS winners with respect to characteristics related to research performance. Although no clear relationship was identified between research performance and scientific contribution, research productivity had a weaker association with scientific contribution than did research influence.

Keywords Research performance · Scientific contribution · National Medal of Science

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Introduction

Excellent scientists are the focus of scientific communities, and they can be identified from their receiving of prestigious scientific awards and notable research performance in their respective fields. Prestigious scientific awards acknowledge scientists with immense contributions to the advancement of science knowledge. The higher the level of the award, the fewer the winners. In fact, numerous studies have preferred the simple and efficient quantitative measure of research performance for identifying outstanding scientists, and even academic institutions used it for making decisions related to promotion, employment, and incentive wages (Abramo et al. 2011). Research performance encompasses research productivity and research influence. Indicators for measuring research productivity are based on the number of publications, and those for measuring research influence focus on the number of citations received for publications. Publications indicate scientists' contributions and research findings. Through publications, scientists can improve their visibility. Accordingly, the higher the number of publications, the higher the possibilities for enhancing visibility, indicating that time affects research productivity and research influence.

Academic awards recognize scholarly research achievements and their research influence. Award recipients are considered to have higher research productivity and research influence than nonrecipients in terms of substantial numbers of publications and citations. This image of scientists winning prestigious awards has been strengthened by empirical research findings highlighting the relation between awards and research performance (de Arenas et al. 2008; Lee et al. 2019; Slutsky and Aytac 2018). Compared to nonrecipients, award recipients share similar characteristics in terms of research performance over the course of their academic career. Therefore, we assume research performance as the basic criterion for an academic award. However, according to the assessment criteria of distinguished scientific awards, the scope of scientific contribution is considered an essential factor for successful publication rather than research performance. The gap between higher research performance and remarkable scientific contribution became the focus of this study. If similar research performance is noted among individual excellent scientists, this may imply that research performance is an essential factor for indicating their scientific contributions. However, if dissimilar research performance is noted among these scientists, this may imply that the scientific contributions that are noticed by award reviewers cannot be reflected substantially through research performance. This may also imply that excellent scientists have various types of research performance with diverse characteristics.

Moreover, not all awards and honors share the same prestigious status (Zheng and Liu 2015). The more prestigious the awards and honors, the fewer the number of recipients and the greater the scientific contribution of the recipients. The large number of nonrecipients of a specific prestigious award indicates that the sample of nonrecipients directly affects the differences in research performance between recipients and nonrecipients. To determine whether excellent scientists have noteworthy research performance, we assessed the research performance of scientists bestowed different levels of prestigious academic awards and honors. To examine the effect of the level of prestigious awards on the research performance of excellent scientists, the nonrecipients (the control group) in this study were also excellent scientists who were recipients of other prestigious awards and honors.

The extant literature has overlooked the research performance of scientists with notable scientific contributions over the course of their academic careers. Moreover, we observed that in previous studies, award winners were categorized under the same group regardless of the differences in their research performance (Borjas and Doran 2015; Chan et al.

2014; de Arenas et al. 2008; Liu et al. 2018; Slutsky and Aytac 2018). Therefore, this study primarily examined whether scientists with excellent scientific contributions have similar research performance in terms of research productivity and research influence during their entire academic career at the individual level. This study also analyzed whether scientists who have received a specific prestigious award have better research performance than scientists without that award. Our results further our understanding of the association among research performance, scientific contributions, and prestigious awards.

Due to the time factor affecting the research performance, individual scientists' research performance was tracked along their entire academic careers. The longitudinal research performances of scientists with significant scientific contributions can help to explore the differences between research performance and scientific contributions. Changes in the annual number of publications and the annual average number of citations received for each publication determined the types of research productivity and academic influence for each scientist. The differences between the types of research productivity and that of research influence further formed the various types of research performances. This study addressed the following research questions:

1. Do excellent scientists have similar types of research productivity?
2. Do excellent scientists have similar types of research influence?
3. Do excellent scientists receiving prestigious scientific awards have higher research performance than other nonrecipients?

Literature review

We divided relevant studies into three categories according to their particular focus regarding the research performance of prestigious award recipients. Studies in the first category have measured only on the research productivity of scientific award winners (de Arenas and Arenas 1999; Yair et al. 2017) or have focused on both their research productivity and the number of citations received within a specific period (de Arenas et al. 2008; de Arenas and Arenas 1999; O'Connell and Rugman 2013; Slutsky and Aytac 2018). These studies featured with a limited of results; only revealed basic figures such as total numbers of publications and citation counts. Although a few focused on comparing the differences in publication productivity and scholarly influence between groups of subjects, most related studies within this category had no further analyses. For example, de Arenas et al. (2008) only presented the total number of papers and citations received by papers indexed by Web of Science (WoS) between 1995 and 2006. They categorized 68 scientists who received the National Prizes for Sciences and the Arts in Mexico into groups by field and age to attain their figures. Slutsky and Aytac (2018) highlighted the number of publications, average total number of citations per recipient, and average *h*-index per recipient from three prestigious awards in the field of chemistry based on published works between 1992 and 2016. No statistical methods were used by either of these two studies to indicate whether significant differences existed between groups of recipients.

Studies in the second category assessed the impact of prestigious awards on research performance by comparing changes in the research performance of excellent scientists before and after they had received awards. Liu et al. (2018) tracked the research performance of 83 Chinese researchers who were granted the 2005 Cheung King Scholars award. Substantial increase and significant differences were identified in number of papers, average number of citations per paper received, number of coauthors per paper, based on two 10-year periods before and after this award. Moreover, these recipients were found to shift to first authors and corresponding authors after receiving this award. Erfanmanesh and Moghiseh (2019) targeted the changes in research performance of 26 recipients of Derek de Solla Price Medal. They compared the differences in the numbers of publications, citations received, research collaborators, and the impact factor of journals in which their articles were published between 5-year before and after this medal. Although increases in various indicators were observed, no significant differences between pre-award and post-award. However, winners of prestigious awards were not always to present greater research influence than pre-award. Borjas and Doran (2015) indicated the decline in publication rates among Fields Medal winners. The Fields Medal is the most prestigious award in the field of mathematics, and it is awarded every 4 years to mathematicians aged below 40 years. The scientists' age and award status affect their publication productivity.

Relatively few studies were found for the third category that comprised studies highlighting the differences in characteristics in research productivity and research influence between recipient and nonrecipient scientists of a specific award. Borjas and Doran (2015) compared the research productivity of two groups of excellent mathematicians: 47 Field Medal recipients and 43 scientists with other major mathematics awards. Before the age of 40 years, both groups of mathematicians had a similar average productivity per year. Chan et al. (2014) observed that obtaining prestigious awards increases citation and publication performance when they obtained awards early in their academic careers. A significant difference in research performance was identified between 27 economic researchers receiving prestigious academic awards of the John Bates Clark Medal (JBCM) and non-JBCM recipients. Three control groups were formed with consideration of the year of PhD attainment, ranking of the university where the PhD degree was granted, year the first paper was published in a top economic journal, and appointment as a Fellow of the Econometric Society. Lee et al. (2019) compared research influence and collaborative research practice between three groups of professors in the College of Engineering at Texas A&M University. The group of professors who had received prestigious awards demonstrated the highest research performance in terms of the citation counts of their top-cited articles, total number of publications and citations, and *h*-index among the three groups of professors.

The aforementioned studies demonstrated that the receipt of awards was associated with better research performance. Recipients of more prestigious awards had better research performance than those of less prestigious awards. However, scientific contributions were not discussed in relation to research performance. Moreover, interindividual differences in the research performance of scientist recipients of prestigious awards have not been assessed.

Methodology

To measure the research performance of excellent scientists, we first defined the excellent scientists. Next, we decided the indicators for measuring research performance. Finally, we determined the data source for collecting data related to research productivity and research influence.

Data collection

We defined recipients of the National Medal of Science (NMS) as excellent scientists in this study. NMS was established by the US Congress in 1959 and is currently administrated by the National Science Foundation. Since 1963, the medal's winners have been selected based on their field and have been awarded their medals by the US President. In the beginning, only award winners in four fields, namely biology, engineering, mathematics, and physics, were granted. Two fields (behavioral and social sciences, chemistry) were not established until 1985. Fifty biological scientists who had received the National Medal of Science (NMS) during a recent 20-year period (1995–2014) were selected as the subject of this study. The last year of winners was 2014 because no NMS winners are announced after 2015.

NMS aims to recognize individuals with outstanding contributions to knowledge to their fields. NMS candidates must first be nominated, following which they must submit less than 10 publications and patents with individual contribution statements. The criteria for selecting winners include the influence of the publication and its contributions to the scientific field, society, education, industry, and the country (National Science Foundation 2018). The impact of individual work on his or her field of science or engineering was valued, which was listed as the first consideration. Due to no clear statement, we could not ensure the association between the impact of work and the number of citations received by publications. Although the impact and influence of work submitted by award recipients relies on their description, we believed that at least partial impact of influential publications can be reflected in citations they received.

Because the complete publication lists for each scientist cannot be obtained, the scope of publications was limited to publications indexed by two large interdisciplinary databases of WoS and the Scopus. To enhance the precision of identifying publications written by 50 biological scientists, we first collected their background information. We referred to variations in author names and affiliations to examine each publication retrieved from WoS and Scopus. By using the winner's names, affiliations, and their brief statement about winning the medal, background information regarding their research output, awards and honors, education, and job experience were collected through their curricula vitae, personal websites, and Internet resources. Considering the differences in the characteristics of the various types of publications, only articles, conference papers, and review articles were deemed as the primary types of research publications, thus becoming the sample publications used in this study. The other type of documents that were most commonly found were editorial materials. No books were retrieved through WoS and only a few books were retrieved from the Scopus for some of the scientists. The first year for counting publications from each scientist varied based on their first publication, whereas the final year was 2017. The final year for counting the annual number of citations received by publications was also 2017. The bibliographical records of publications obtained from the two databases were used for related analyses. Each bibliographical record included the title, author name and affiliation, document type, publication year, source, and total number of citations. The annual number of citations that were received by the sample publications were available and collected in a separate file.

Data processing

Seven indicators were used to measure the research performance of each scientist. Three indicators were related to research productivity, three were related to research influence, and one was related to a combination of research productivity and research influence. For the three indicators related to research productivity, the first was the total number of publications during the entire academic career. The second indicator, annual research productivity, was used to demonstrate the annual number of publications for each scientist. Each scientist may have variations in length of academic careers and senior scientists are believed to take advantage of time and produce higher number of publications than other scientists. To reduce the affection brought by time, we focused on the annual number of publications. The third indicator—the average number of publications per year—was calculated to represent the average research productivity for the entire academic career of individual scientists. Differences between the annual number of publications and the average research productivity indicated whether the average number of publications per year is an accurate indicator of research productivity for most years. The average annual number of publications per year was not an accurate indicator for scientists with considerable fluctuations in yearly number of publications.

The fourth and fifth indicators were related to research influence and were the total number of citations received by publications and the average number of citations per publication, respectively. This figure of average citation per publication hides the most influential work with the highest number of citations. To reduce the affection of time in the count of citations, the sixth indicator, annual research influence per publication, referred to the annual average number of citations received for each publication. For example, if a scientist had 10 publications by 2000 and only two of them received 10 citations in 2000, then the annual average number of citations in 2000 for the scientist would be five (10/2). We assumed that these excellent scientists had at least one work with substantial number of citations to present their influence. Although most publications published by a scientist may not receive substantial number of citations, the higher annual average number of citations per publication is still evident in certain period of time. The annual average number of citations received for each publication along a scientist's entire academic career is a useful indicator for us to observe the longitudinal change in research influence of a scientist. The final indicator, the *h*-index, revealed the combination of the number of publications and number of citations received (Hirsch 2005).

To collect data related to scientists' publications and the number of citations they receive, citation index databases were considered. Although WoS and Scopus are two large interdisciplinary citation index databases, Scopus covers a larger number of journals than does WoS. To obtain a more complete list of publications for each scientist, the use of two databases is more appropriate than the use of only one database because of the differences in database coverage. Because the annual number of citations that were added to individual publications was available from WoS for further analysis and Scopus did not provide data on citations before 1970, the numbers of publications and citations received by publications were collected from WoS instead of Scopus. Moreover, only three primary types of scholarly documents formed the sample of publications: original articles, review articles, and conference papers.

After reviewing the background information of 50 biological scientists, including the awards and honors they had received, each scientist was found to have obtained the fellowship granted by the American Academy of Arts and Sciences (AAAS). Scientists who receive the AAAS fellowship are widely considered to be outstanding and influential. Moreover, most scientists have received the NMS after they were past the age of 65 years. This implies that bulk of their research performance in their academic careers occurred before they received the NMS. Therefore, we decided to elaborate the focus of their research by observing changes in their research performance during three periods, namely before obtaining the AAAS fellowship, after obtaining the AAAS fellowship and before receiving the NMS, and after receiving NMS. For example, in Fig. 1, the year when a scientist acquired the AAAS fellowship was marked at 0 and with a normal vertical line on the horizontal axis. The point with the bold vertical line denoted the year when a scientist received NMS. Three periods observed in this study were clearly separated.

Changes in the annual number of publications (trend in research productivity) and in the annual average number of citations received by each publication (trend in research influence) were presented for each period. For example, in Fig. 1, the bold horizontal line represents the annual number of publications, and the dotted line represents the annual average number of citations received per publication. To compare the trends in research productivity and research influence for the three periods for each scientist, they are presented in the same figure. However, because of substantial differences in the annual number of citations received by publications, we could not plot them on a chart. For example, one scientist had eight publications by 1983. In 1983, four out of eight publications received a total of 12 citations. By 2017, this scientist had 486 publications. In 2017, 407 publications received a total of 6675 citations, ranging between 1 and 393 citations per publication. The annual average number of citations per publication was 1.5 (12/8) in 1983 and 16.4 (6675/407) in 2017. The conversion of regular numbers into log values fails to reveal large differences between numbers (the base-10 logarithm of 12 is 1.07 and of 6675 is 3.82). After evaluating different methods of presenting trends in research influence, we used the annual average number of citations per publication instead of the annual number of citations received by publications or its logarithm.

The trends in research productivity and research influence during each period deduced the specific types of research productivity and that of research influence. Each type was labeled with three numbers. Code 0 refers to no change in the trend of research productivity/research influence, code 1 refers to an increasing trend in research productivity/research influence, and code 2 refers to a decreasing trend in research productivity/research influence. As indicated in Fig. 1, a scientist typed as 122 for research productivity and research influence has an increasing trend in the first period and a decreasing trend in the second and third periods. The specific type of trend was identified immediately for some cases. For other cases with several fluctuations during a period, we referred to the trend line added to the Excel chart. The samples indicating no trends include figures related to research productivity and research influence that include less than 3 years in a single period.

To further highlight the characteristics of NMS winners and explore the effect of receiving NMS on the research performance of scientists, scientists not awarded the NMS (the control group) were compared with 50 biologists awarded the NMS. Although studies have reported that award recipients have better research performance than nonrecipients, the

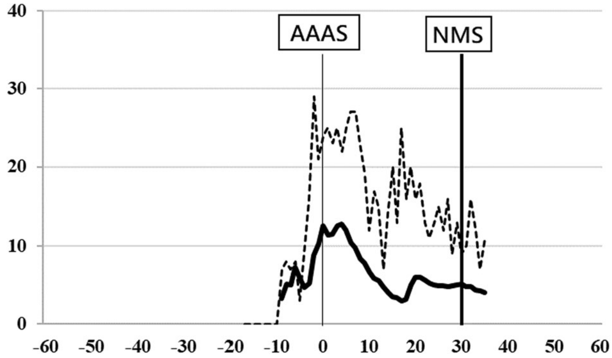

Fig. 1 One example figure for type 122

criteria they used for constructing control groups varied (Borjas and Doran 2015; Chan et al. 2014), and considerable variations in this regard for a specific award lead to differences in research results. In the present study, the control group included only scientists who had received prestigious awards and honors but not the NMS. In other words, they were also excellent scientists in terms of the awards and honors obtained. Awards and honors differ in academic prestige. Although the AAAS fellowship is a prestigious honor, the NMS is even more prestigious. We targeted the differences in research performance between recipients of the AAAS fellowship and recipients of both the AAAS fellowship and the NMS. To reduce the influence of other factors relevant to individual scientists, receipt of the AAAS fellowship, field, nationality, and age were the variables used to select the members of the control group.

Members included in the control group were required to be the US citizens, recipients of the AAAS fellowship but not the NMS in the same field (biology) and year as recipients of both the NMS and AAAS fellowship, and have a similar age to that of NMS winners. The requirement of being a US citizen was introduced to reduce the influence of nationality. To reduce the influence of time on research performance, we refrained from comparing the research performance of NMS recipients and non-NMS recipients who differed considerably in academic career duration or stage. Therefore, scientists in the control group were required to have a similar age to that of NMS winners in addition to being recipients of the AAAS fellowship in the same year. When the number of candidates in the control group was higher than that of NMS winners, candidates having the closest age to those of NMS winners with the AAAS fellowship in the same year were considered. For instance, an NMS winner acquired the AAAS fellowship at the age of 50 years, and two scientists acquired the same fellowship at the ages of 53 and 58 years, respectively. The scientist acquiring the AAAS fellowship at the age of 53 years was selected as a control group member. These requirements for the control group helped us to compare the research performance of scientists with similar ages who obtained the AAAS fellowship in the same field and year and had the same nationality. Other requirements considered, such as institutional affiliation and research interests, were not used because of heterogenous or incomplete data. In addition, one NMS winner was paired with one scientist in the control group because a large difference in age existed between a limited of number of American biological scientists acquiring the AAAS fellowship in the same year as NMS winners with the AAAS fellowship. Moreover, most of the remaining 27 NMS winners between 1995 and 2004 lacked qualified control members, they were excluded in the comparison analysis of the two groups. Accordingly, 23 members of the control group were paired with 23 NMS winners during 2005–2014 for comparing their research performance.

Results

Age of NMS recipients

The average age of NMS winners was approximately 69 years, ranging between 55 and 90 years. Moreover, the average age was approximately 50 years when they obtained the AAAS fellowship, with a wide age range between 29 and 80 years. This finding revealed that receiving NMS is a higher achievement than acquiring the AAAS fellowship. Table 1 shows that most biological scientists were NMS winners at the end of their academic careers, indicating that these scientists have contributed their lives to research before their contributions were acknowledged. Only five NMS winners were under the age of 60 years. The length of time between receiving the AAAS fellowship and NMS ranged between 1 and 40 years. Only three scientists in the study sample received NMS before the AAAS fellowship. The other 47 scientists received NMS on an average of approximately 20 years after the AAAS fellowship. In addition, they were affiliated with 30 institutions. The Massachusetts Institute of Technology had the highest number of scientists (six scientists).

Annual average research performance

The number of publications (articles, conference papers, and review articles) of each scientist covered by WoS ranged between 19 and 1600, as illustrated by the dots on the right vertical axis in Fig. 1. The annual average number of publications for each scientist ranged between 0.30 and 24.24 (Table 1). Articles constituted an average of approximately 88.2% of publications per scientist, ranging between 69.8% and 100.0%. In Fig. 2, one dot represents one scientist, and the horizontal axis represents time. The vertical line located at 0 marks the year in which the AAAS fellowship was received. The location of each dot relative to the zero point indicates the specific year in which the respective scientist obtained the NMS. The finding revealed that only three scientists received NMS before the AAAS fellowship. The scientist with the highest research productivity had 1600 publications and received NMS after 33 years with the AAAS fellowship.

Figure 2 depicts the annual average number of publications for each scientist with the dotted line. The figure illustrates that the annual average research productivity per scientist peaked when scientists have acquired the AAAS fellowship for 20 years. Moreover, the bold solid line indicates the annual average number of citations per publication for each scientist according to WoS. Excluding the two ends of the bold solid line, similar trends were observed between annual average research productivity (the dotted line indicating the annual average number of publications per scientist) and annual average research influence (the solid bold line indicating the annual average number of citations received for each publication). However, considering that the average does not indicate the actual research performance of the 50 scientists. Accordingly, different from the focus of previous studies, we focused on individual research performance because significant differences in research performance may exist at individual levels.

Comparison of research productivity and research influence

Figure 3 shows the types of research productivity and that of research influence for each scientist. Wherein the bold solid line refers to research influence measured by the annual average number of citations received by each WoS publication, and the dotted line refers to the annual number of publications indexed by WoS.

The categorization of research productivity and research influence helped us to determine whether a given scientist was classed in the same category for research productivity and research influence. Figure 3 shows that the types of research productivity and that of research influence were not similar for some scientists at the individual level. Considering the changes in the annual number of publications during three periods (before AAAS fellowship, between AAAS fellowship and NMS, and after NMS), the research productivity of 50 biological scientists was categorized into eight types. Similarly, 10 types of research influence were generated on the basis of changes in annual average number of citations per publication during the three periods. As shown in Table 2, the distributions of the 50

Table 1 List of scientists

Nos.	Name	Institution	Age (NMS)	Age (AAAS)	*P*	Ave *P*	*C*	Ave *C*
1	Robert A. Weinberg	Whitehead Institute for Biomedical Research; Massachusetts Institute of Technology	55	45	317	7.20	138,650	437.38
2	Elaine Fuchs*	Howard Hughes Medical Institute; Rockefeller Univ.	58	44	305	8.47	47,820	156.79
3	Francis S. Collins*	Natl. Institutes of Health	58	48	456	10.13	111,465	244.44
4	May Berenbaum*	Univ. of Illinois Urbana-Champaign	59	43	226	6.28	11,232	49.70
5	Ann M. Graybiel	Massachusetts Institute of Technology	59	49	235	5.34	28,934	123.12
6	Susan Lee Lindquist*	Massachusetts Institute of Technology	60	47	287	7.76	50,385	175.56
7	Phillip A. Sharp	Massachusetts Institute of Technology	60	39	358	8.14	72,903	203.64
8	David Baltimore	California Institute of Technology	61	36	580	10.55	125,784	216.87
9	Lynn Margulis	Univ. of Massachusetts	61	60	127	2.89	3306	26.03
10	J. Craig Venter*	J. Craig Venter Institute	62	55	235	5.22	78,436	333.77
11	Harold Varmus	Memorial Sloan-Kettering Cancer Center	62	49	324	6.75	53,700	165.74
12	Nancy C. Andreasen	Univ. of Iowa	62	64	385	9.39	44,743	116.22
13	Jared Diamond	Univ. of California, Los Angeles	62	36	194	3.53	14,477	74.62
14	Rakesh K. Jain*	Harvard Medical School; Massachusetts General Hospital	63	58	486	11.30	78,042	160.58
15	Sallie W. Chisholm*	Massachusetts Institute of Technology	64	45	148	3.79	20,291	137.10
16	Robert J. Lefkowitz*	Howard Hughes Medical Institute; Duke Univ.	64	45	694	14.77	116,120	167.32
17	Nina V. Fedoroff*	Pennsylvania State Univ.	64	47	87	1.89	6197	71.23
18	Mario R. Capecchi	Univ. of Utah	64	72	198	3.81	25,436	128.46
19	Peter H. Raven	Missouri Botanical Garden and Washington Univ.	64	41	116	2.58	4740	40.86
20	Anthony S. Fauci*	Natl. Institutes of Health	65	51	790	15.19	109,319	138.38
21	Solomon H. Snyder	Johns Hopkins Univ.	65	41	869	17.38	159,194	183.19
22	Gene E. Likens	Institute of Ecosystem Studies	66	44	308	5.40	29,364	95.34
23	Stanley Prusiner*	Univ. of California, San Francisco	67	51	511	12.46	72,503	141.88
24	J. Michael Bishop	Univ. of California, San Francisco	67	48	297	6.75	47,540	160.07

Table 1 (continued)

Nos.	Name	Institution	Age (NMS)	Age (AAAS)	*P*	Ave *P*	*C*	Ave *C*
25	Francisco J. Ayala	Univ. of California, Irvine	67	43	380	7.31	17,444	45.91
26	Mary-Claire King*	Univ. of Washington	68	53	223	4.55	27,723	124.32
27	Rudolf Jaenisch*	Whitehead Institute for Biomedical Research	68	50	495	9.71	109,207	220.62
28	Lubert Stryer*	Stanford Univ.	68	37	117	2.02	22,386	191.33
29	George F. Bass	Texas A&M Univ.	69	80	30	0.52	256	8.53
30	James D. Watson	Cold Spring Harbor Laboratory	69	29	56	0.84	15,977	285.30
31	Bruce N. Ames*	Univ. of California, Berkeley	70	42	360	5.54	98,478	273.55
32	Lucy Shapiro*	Stanford Univ.	71	52	209	3.87	15,061	72.06
33	Bert W. O'Malley*	Baylor College of Medicine	71	60	660	12.45	65,012	98.50
34	Alexander Rich	Massachusetts Institute of Technology	71	35	300	4.41	31,293	104.31
35	Rita R. Colwell*	Univ. of Maryland	72	68	587	10.30	32,446	55.27
36	James E. Darnell	Rockefeller Univ.	72	43	319	5.06	66,869	209.62
37	Carl R. Woese	Univ. of Illinois	72	57	244	3.87	46,676	191.30
38	Simon A. Levin*	Princeton Univ.	73	51	256	4.74	25,239	98.59
39	Leroy Hood*	Institute for Systems Biology	73	44	709	16.11	96,156	135.62
40	Janet D. Rowley	Univ. of Chicago	73	66	361	6.56	35,113	97.27
41	Bruce Alberts	Univ. of California, San Francisco	74	40	131	2.67	16,538	126.24
42	Ralph Brinster*	Univ. of Pennsylvania	78	54	313	5.69	42,987	137.34
43	Thomas E. Starzl	Univ. of Pittsburgh	78	45	1600	24.24	86,037	53.77
44	Charles Yanofsky	Stanford Univ.	78	39	321	4.86	21,174	65.96
45	Stanley Falkow*	Stanford Univ.	80	54	272	4.95	37,394	137.48
46	Victor A. McKusick	Johns Hopkins Univ.	80	67	289	4.25	26,201	90.66
47	Torsten N. Wiesel*	Rockefeller Univ.	81	43	73	1.24	41,128	563.40
48	Evelyn M. Witkin	Rutgers Univ.	81	57	51	0.72	5912	115.92
49	Ruth Patrick	Academy of Natural Sciences	89	69	20	0.43	221	11.05

Table 1 (continued)

Nos.	Name	Institution	Age (NMS)	Age (AAAS)	*P*	Ave *P*	*C*	Ave *C*
50	Norman E. Borlaug	Texas A&M Univ.	90	62	19	0.30	354	18.63

*Refers to 23 scientists whose research performance was further compared with that of non-NMS scientists in the control group; *P* refers to the total number of three types of publications; Ave *P* refers to the annual average number of three types of publications; *C* refers to the total number of citations received by three types of publications; Ave *C* refers to the average number of citations received by each of three types of publications

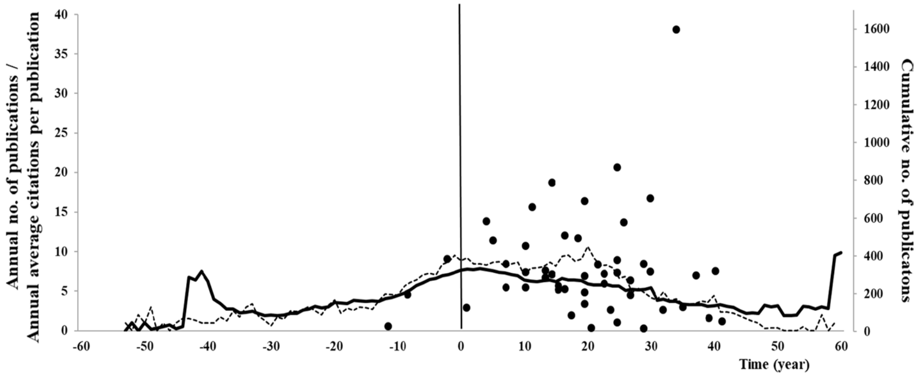

Fig. 2 Annual average research productivity and research influence for each scientist

NMS recipients across all types of research productivity and research influence revealed the primary types. Types 112 and 122 of research productivity were found for 30 scientists. An increasing trend was observed during the first and second periods for Type 112, and a decreasing trend was observed during the third period (i.e., after receiving NMS). An increasing trend was observed during the first period for Type 122, and a decreasing trend was noted during the other two periods. Moreover, three scientists had low research productivity, with no observed trends during the three periods (Type 000). Scientists accumulate their publications (in the first stage) before receiving the AAAS fellowship. However, the difference in length of time affected the direction of the trend line of research productivity and research influence in the first stage. For scientists with a longer length of time such as over 20 years, a large fluctuation in annual figures led to a decreasing trend in research performance. Accordingly, the first period of these cases were changed from code 2 (a decreasing trend) to code 1 (an increasing trend). Regarding the 10 types of research influence, 24 scientists (48%) belonged to Type 122. Type 121 was the second most common type (9 scientists, 18%), followed by Type 112 (8 scientists, 16%). Based on differences in the types between research productivity and research influence for each scientist, we observed that 21 scientists featured the same six types for both research productivity and research influence, namely 000, 110, 112, 120, 121, and 122. This indicates that most scientists did not have the similar changes in research productivity and research influence over time. In addition, although no association was observed between research productivity and research influence types for most scientists, some unique combinations of research productivity and research influence types were identified, such as 000 and 120.

To explore whether certain factors affect the categorization of research productivity and research influence, we adopted two methods for grouping the 50 scientists and then performed intragroup and intergroup comparisons of research performance. First, we considered the effect of the age of scientists on their research performance. The decreasing trend in the annual number of publications for scientists receiving NMS after their retirement or at the end of their academic careers is standard. Based on scientists' age of receiving the AAAS fellowship and NMS and the length of time between the two honors, 50 scientists were divided into six groups. As indicated in Fig. 2, Group 1 comprised 11 scientists (#1–11), Group 2 comprised 10 scientists (#12–21), Group 3 comprised 7 scientists (#22–28), Group 4 comprised 6 scientists (#29–34), Group 5 comprised 8 scientists (#35–42), and Group 6 comprised 8 scientists (#43–50). Scientists in groups 1

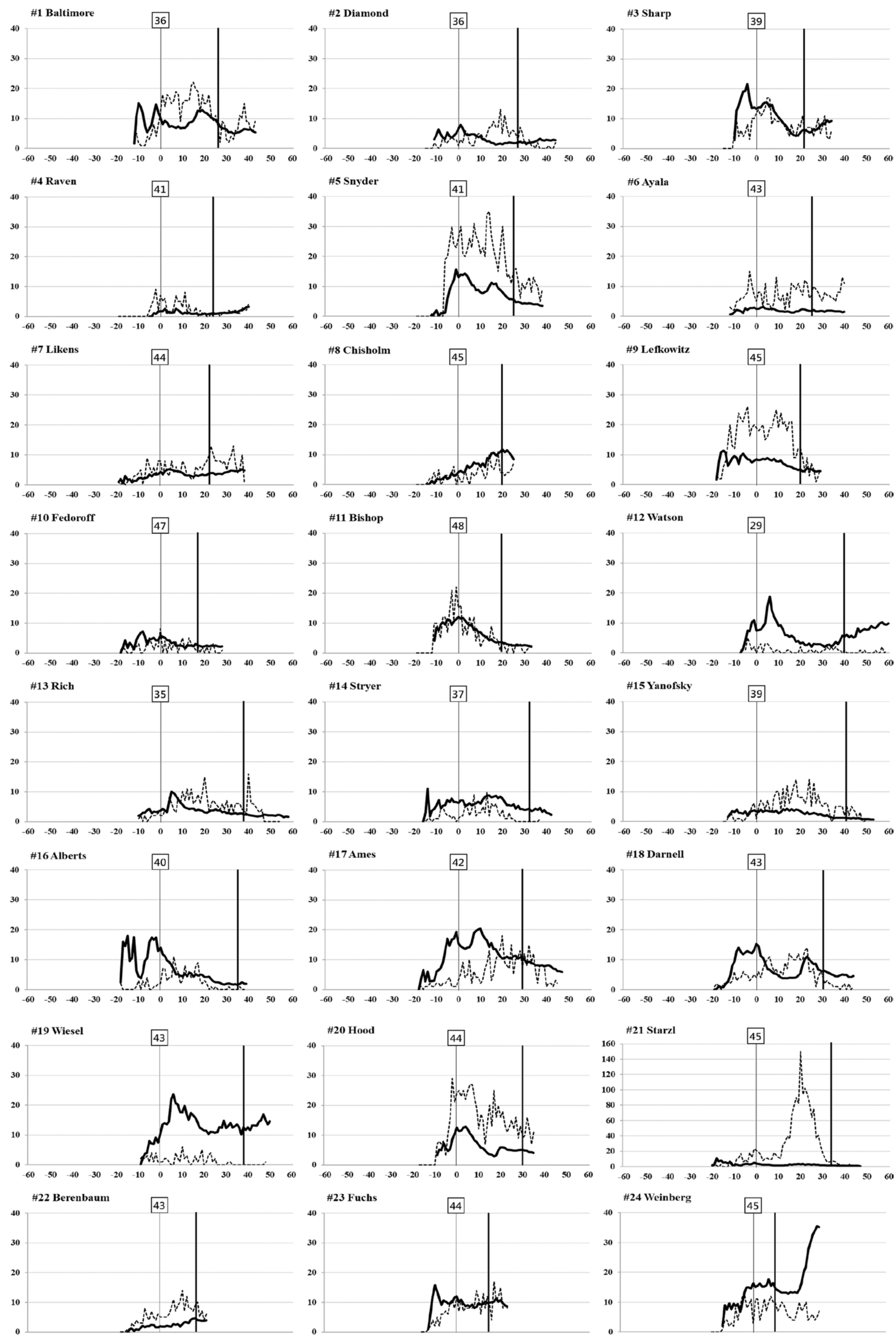

Fig. 3 Research performances for individual scientists. *Notes* Bold lines refer to research influence (annual average number of citations received by each publication); dotted lines refer to research productivity (annual number of publications); the horizontal axis represents time; the zero point is a reference point for conveying the year in which a given scientist received the AAAS fellowship

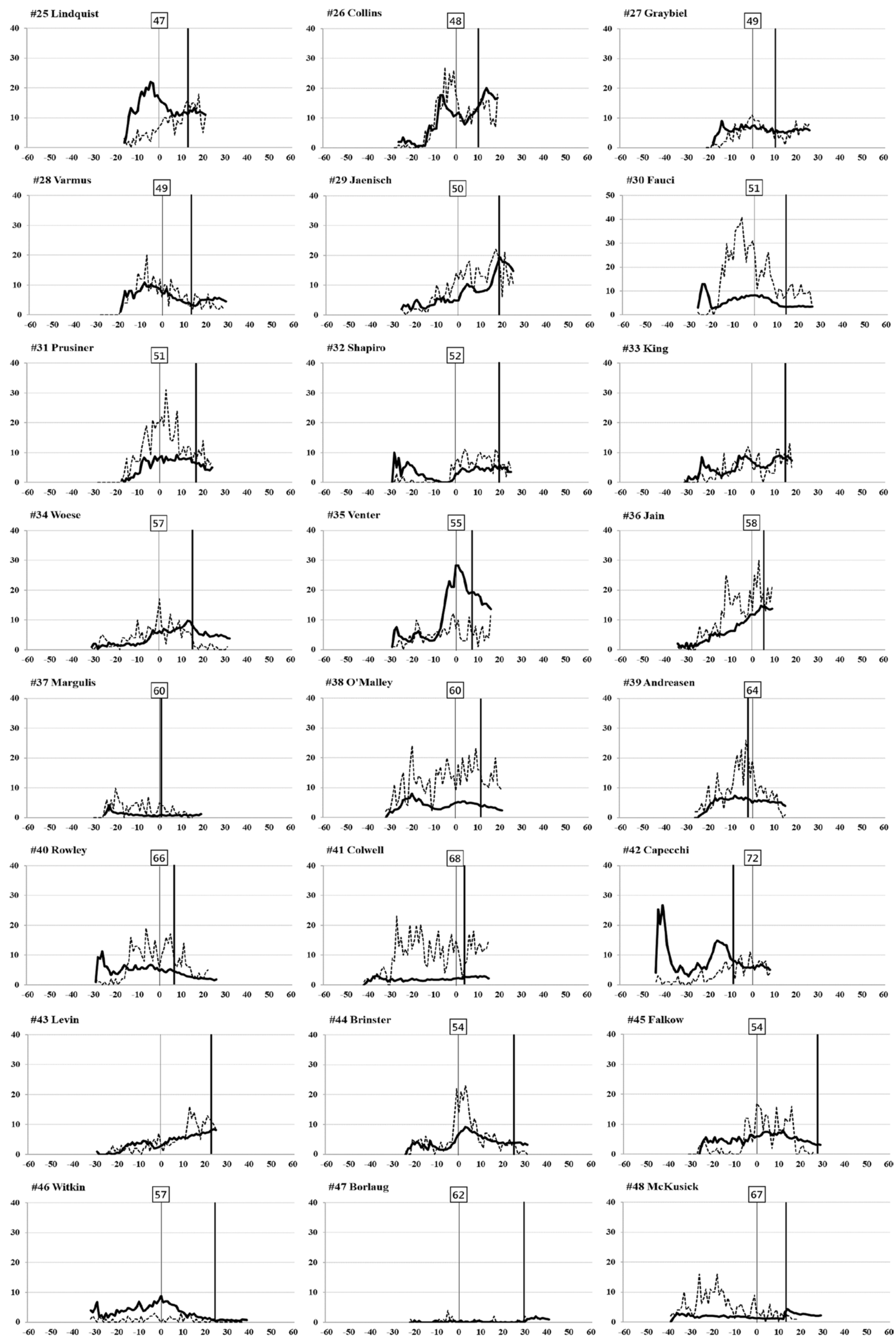

Fig. 3 (continued)

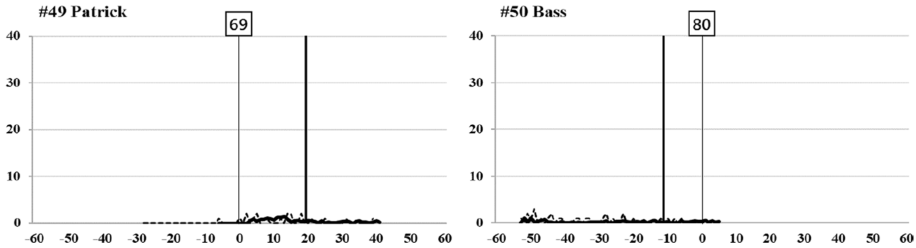

Fig. 3 (continued)

Table 2 Types of research productivity and research influence

Type	Research productivity	Research influence
122	16	24
112	14	8
121	6	9
111	4	3
110	3	2
000	3	1
120	3	1
102	1	0
001	0	1
010	0	1
100	0	1
	50 (100%)	50 (100%)

and 2 received the AAAS fellowship before the age of 45 years, which is lower than the average age of receiving the AAAS fellowship (i.e., 50 years). Furthermore, these scientists acquired NMS at least 17 years later. Most scientists receiving the AAAS fellowship before the age of 50 years received NMS early (i.e., before the age of 69 years, which is the average age of receiving NMS per scientist); however, these scientists had a longer time to acquire NMS than other scientists. Most scientists in groups 1 and 2 had the highest research influence in the beginning of their academic careers. Although an increase in the annual number of publications was observed, the annual average research influence of these scientists did not increase over time.

As presented in the upper section of Table 3, because the six groups were divided according to both ages when a scientist received the AAAS fellowship and NMS and the length of time between the receiving of the two honors, one-way ANOVA results revealed significant differences between the groups for the aforementioned age and between the groups for the aforementioned length of time. However, the groups did not significantly differ with respect to the nine research-performance-related indicators, namely total productivity (total number of publications), average productivity (average number of publications per year per scientist), average productivity before the age of 66 years, average productivity after the age of 65 years, total influence (total number of citations), average influence (average number of citations per publication per scientist), average *h*-index (average *h*-index per scientist), average highest citation (average number of citations between scientists, with each scientist having the number of citations had by their most-cited publication), and

Table 3 Comparison of research-performance-related characteristics among six groups of scientists

	G1	G2	G3	G4	G5	G6
Number of scientists	11	10	7	6	8	8
Average age receiving AAAS*	42.3	39.7	46.4	52.3	62.9	61.8
Age range receiving AAAS	36–48	29–45	43–49	50–57	55–72	51–80
Average age receiving NMS*	64.0	73.4	58.7	68.5	66.0	80.0
Age range receiving NMS	60–67	68–81	55–62	65–72	61–73	69–90
Average length of time between two honors*	21.7	33.7	12.3	16.2	5.6	21.0
Total productivity	87–869	56–1600	226–456	209–790	127–660	19–313
Average productivity	7.5	6.7	7.4	8.3	7.7	2.7
Average productivity before the age of 66	8.3	7.2	7.6	8.51	7.7	3.1
Average productivity after the age of 65	5.0	5.6	6.4	8.3	8.9	2.6
Total influence	4740–159,194	15,977–98,478	11,232–138,650	15,061–109,319	3306–78,436	221–42,987
Average influence	126.9	200.9	193.2	148.1	127.0	77.3
Average *h*-index	110.5	96.4	114.7	123.5	98.1	54.5
Average highest citation	1897.2	4400.9	4605.9	2811.8	2889.4	2153.5
Average number of highly cited publications	4.7	5.6	10.6	7.2	6.4	1.1
Number of scientists	8	9	9	8	9	7
Average age receiving AAAS	55.6	45.8	51.3	54.6	47.8	44.6
Age range receiving AAAS	29–80	36–67	35–72	47–66	39–60	36–51
Average age receiving NMS	73.4	70.6	68.2	68.0	66.3	64.4
Age range receiving NMS	61–90	59–81	59–78	60–80	58–78	55–73
Average length of time between two honors	20.5	24.8	18.7	13.9	18.6	19.9
Total productivity*	19–127	73–380	148–584	235–385	305–1600	317–869
Average productivity*	1.3	4.0	5.2	6.6	10.9	13.0
Total influence*	221–15,977	11,232–41,128	20,291–46,676	35,113–78,436	47,820–111,465	96,156–138,650
Average influence	72.2	145.8	113.9	165.4	171.4	214.2

Table 3 (continued)

	G1	G2	G3	G4	G5	G6
Average *h*-index*	22.6	67.6	87.7	112.3	137.33	176.1
Average highest citation*	1323.1	2778.3	1993.8	3145.1	3712.2	6032.6
Average number of highly cited publications	0.6	2.1	3.0	6.0	9.8	14.0
Average productivity before the age of 66*	1.6	4.3	5.1	7.6	10.8	14.2
Average productivity after the age of 65*	0.7	3.1	6.0	4.9	11.7	9.4

*Refers to $p < 0.05$

average number of highly cited publications (average number of publications with more than 1000 citations per scientist).

Because of the absence of the difference, we divided 50 scientists into six groups by using another requirement: the *h*-index, which measures quantity (publications) and impact (citations). According to the lower part of Table 3, Group 1 comprised 8 scientists (#4, 10, 12, 37, 38, 39, 49, and 50), Group 2 comprised 9 scientists (#2, 3, 6, 14, 16, 19, 22, 32, 43, and 48), Group 3 comprised 9 scientists (#7, 8, 13, 15, 27, 33, 34, 41, and 42), Group 4 comprised 8 scientists (#11, 25, 28, 35, 39, 40, 44, and 45), Group 5 comprised 9 scientists (#3, 17, 18, 21, 23, 26, 31, 36, and 38), and Group 6 comprised 7 scientists (#1, 5, 9, 20, 24, 29, and 30). With the exception of the average *h*-index, significant differences were observed in six indicators, namely total productivity, average productivity, total citations, average highest citation, average productivity before the age of 66, and average productivity after the age of 65.

Comparison of NMS winners and non-NMS winners

To examine the effect of NMS, the research performance of the control group consisting of 23 non-NMS winners (Table 4) was compared with that of 23 NMS winners. The 23 NMS nonrecipients had similar academic backgrounds and careers to those of their NMS counterparts, including academic field, nationality, age, and year of receiving the AAAS fellowship. Moreover, Harvard University had the largest number of scientists in the control group (5 scientists). Table 5 shows that although the average productivity of NMS winners was higher than that of non-NMS scientists, no significant differences were observed in indicators related to average productivity. Significant differences existed in indicators related to research influence, namely average influence, average *h*-index, and average number of highly cited publications.

Discussion and conclusion

The study results revealed individual-level differences in annual changes in the research performance between 50 biologists who received the NMS between 1995 and 2014. This study differs from prior research, which analyzed the research performance of award receipts at only the aggregate level (Chan et al. 2014; Erfanmanesh and Moghiseh 2019; Liu et al. 2018) and revealed a limited number of results for each scientist (de Arenas and Arenas 1999). The age of the 73 scientists in this study ranged between 65 and 105 years in 2018. We considered their publications before 2018. Therefore, the study investigated the research performance of most of the scientists' entire academic career. A total of 16,928 WoS publications were published between 1946 and 2017. We analyzed their citation counts and examined the yearly decline in productivity after the conventional retirement age of 65 years. We also analyzed annual changes in research performance before and after the receiving of honors. Of the 50 NMS winners, the annual productivity of 15 scientists after the age of 65 years was higher than that before the age of 65 years. Only one scientist had the last publication at the age of 64 years. Other 49 scientists continued to publish after the age of 65 years. The length of time for publishing articles after the age of 65 years and before 2018 ranged between 2 and 45, indicating that most excellent scientists had an academic career beyond the age of 65 years.

Table 4 List of control group of scientists

Nos.	Name	Institution	Age (AAAS)	P	Ave P	C	Ave C
1	Michael Tran Clegg	Univ. of California, Irvine	45	157	3.41	8111	64.89
2	Roger D. Kornberg	Stanford Medical School	44	229	5.59	28,292	125.19
3	Philip Warren Majerus	Washington Univ. in St. Louis	48	254	4.54	25,814	110.79
4	Klavs Flemming Jensen	Massachusetts Institute of Technology	43	430	9.56	24,621	66.36
5	Douglas Joel Futuyma	Stony Brook Univ.	49	54	1.08	5317	98.46
6	Hector Floyd DeLuca	Univ. of Wisconsin, Madison	47	1010	16.03	64,170	64.04
7	Sarah Blaffer Hrdy	Univ. of California, Davis	39	28	0.65	1649	61.07
8	Tony Hunter	Salk Institute for Biological Studies	36	635	12.70	98,251	196.11
9	Paul Randolph Gross	Univ. of Virginia	60	491	7.44	4164	48.42
10	Ray Franklin Evert	Univ. of Wisconsin, Madison	55	142	2.49	4564	32.60
11	David Lorn Garbers	Univ. of Texas Southwestern Medical Center	49	215	5.12	18,460	86.26
12	Edward Everett Harlow, Jr.	Harvard Medical School	64	122	3.21	30,304	252.53
13	Felton James Earls	Harvard Medical School	36	110	2.39	10,994	100.86
14	Wayne Lester Hubbell	Univ. of California, Los Angeles	58	240	4.80	21,871	91.51
15	James Edward Rothman	Yale Univ.	45	364	7.91	45,115	186.43
16	Michael J. Welsh	Univ. of Iowa Carver College of Medicine	45	769	17.88	42,712	91.46
17	Joe Claude Bennett	University of Alabama Medical School; BioCryst Pharmaceuticals, Inc.	47	163	2.76	1599	18.81
18	Stuart Arthur Kornfeld	Washington Univ. in St. Louis	72	256	4.34	31,062	123.26
19	Charles Clifton Richardson	Harvard Medical School	41	258	4.69	22,664	91.76
20	Marc Wallace Kirschner	Harvard Medical School	51	398	8.47	76,380	208.12
21	Herbert Pardes	New York-Presbyterian Hospital	41	46	0.90	764	16.61
22	Jack Leonard Strominger	Harvard Univ.	44	744	10.48	82,977	111.53
23	C. Ronald Kahn	Joslin Diabetes Center; Harvard Medical School	51	695	12.64	83,062	128.58

Table 5 Comparison of research performance between NMS and non-NMS winners

	NMS winners	Non-NMS winners	*p* value
Number of scientists	23	23	
Average age receiving AAAS	49.6	50.9	0.525
Average productivity	8.2	6.5	0.220
Average productivity before the age of 66	7.9	6.3	0.317
Average productivity after the age of 65	7.3	4.9	0.138
Average influence*	162.5	103.3	0.026
Average *h*-index*	109.1	80.3	0.027
Average number of highly cited publications*	6.7	3.0	0.031
Average highest citation	3260.4	1986.6	0.075

*Refers to $p < 0.05$

The study results are not consistent with those of Chan et al. (2014). Chan et al. (2014) observed increased research productivity and research influence among scientists after they received prestigious scientific awards. The difference in the study results may be because the scientists were awarded NMS during their later years. A study indicated an inverted U-shaped relation between scientists' age and research productivity (Perlin et al. 2017). The study observed that the scientists were not as productive during the later periods of their academic careers. Receiving NMS is considered a higher achievement than acquiring the AAAS fellowship. Accordingly, scientists were awarded NMS after acquiring the AAAS fellowship, excluding three scientists. As per the study results, 26 scientists reached the peak of their research productivity after receiving the AAAS fellowship and before receiving NMS. Moreover, 20 scientists reached the peak of their research productivity before acquiring the AAAS fellowship. Only four scientists had the highest research productivity after receiving NMS. These results indicate that the excellent scientists did not reach the peak of their academic careers at a similar age or stage.

The annual average research influence per publication did not reveal the actual research influence for most scientists owing to the skewness of citations. Some NMS scientists had no substantial research influence during their academic careers; decreasing trends were observed in their research influence before receiving NMS. Regarding the research influence of each publication, excluding 4 scientists, 26 scientists published at least one article with over 500 cumulative citations until 2017. Two scientists published an article with more than 10,000 cumulative citations. The annual average number of citations for the publication with the highest cumulative citations among the 26 scientists ranged between 15 and 2782. This finding revealed that most biological scientists who received NMS are highly influential researchers. Although scientific contribution has various definitions, Aksnes and Rip (2009) reported a consensus among scientists in natural sciences that citation counts validly reflect a publication's scientific contribution even if scientific contribution cannot always be measured by the number of citations. In addition, not all publications of these 50 scientists are covered by WoS. The research influence of each scientist was undermined.

Among four scientists who indicated low research productivity (annual number of publications lower than 4) and low research influence (publications with less than 500 citations), two scientists were found to have influential books, based on a substantial number of citations obtained from the reference search function provided by WoS. However, books are not one of the primary types of research that are indexed by WoS and Scopus. Therefore, the research performance of scientists who published books were underestimated. Biological scientists tend to publish journal articles (Bourke and Butler 1996; Mutz et al. 2013). Most researchers in the fields of science and technology demonstrate their research results and influence through research articles. However, few scientists' research performance may be primarily published through books. Therefore, books must be considered for measuring the research performance of scientists. Moreover, differences continue to exist between the subfields within biology. One biological scientist may specifically focus on underwater archaeology, a rare and small profession. This may lead to his books having no substantial citations, and therefore, be incomparable with the research influence of other scientists. Another biological scientist may alleviate the human hunger problem, and therefore, may have contributed substantially to help people around the world. However, this type of contribution may not be sufficiently reflected in their research publications. Research results not only serve the scientific community. Improving the quality of life and resolving social problems are goals of scientific research. Therefore, some aspects of research performance are not measured using bibliometric indicators related to research performance. This was reported by Greehalgh et al. (2016) who reviewed studies on the measurement of research impact. They found that research impact is a complex concept and that various approaches to measuring research impact are impracticable. Although research influence has been explored using a bibliometric perspective, the quantification of research influence is still a big challenge for scientometric researchers.

Considering the inconsistency among the types of research performance of 50 NMS winners, we divided 50 NMS winners into groups. Scientists were grouped according to the two criteria of their age when they received both the AAAS fellowship and the NMS and the length of time between the receiving of the two honors. However, no statistically significant differences in research performance were observed between these newly formed groups, indicating that the age when honors are received has no association with research performance. Subsequently, we used *h*-index to divide 50 scientists into six groups according to their research performance. Significant differences were observed with respect to the average number of publications per year (including those published before and after the age of 65 years) between half of all possible pairs of the groups, but no significant differences were observed with respect to the ages when honors are received. We also grouped 50 scientists according to other criteria, including age, the number of citations of the scientist's most-cited article, average number of citations per publication, and age when receiving the NMS. No inconsistent findings were obtained for these alternative grouping criteria. This consistency implies that research performance plays a minor role in the recognition of the scientific contributions of NMS winners. Moreover, we observed that better research performance did not entail an earlier reception of the NMS.

Award winners tend to excel and have a greater research influence than nonrecipients; related studies have reported that award winners had better research performance than did nonrecipients (Borjas and Doran 2015; Chan et al. 2014). Because the diverse differences in characteristics among a large number of nonrecipients, we compared the research performance of 23 NMS winners during 2005–2014 at the aggregate level with that of another 23 biologists who did not receive the NMS. The control group in this study comprised scientists who received the AAAS fellowship and other honors. Therefore, they also had substantial research performance. The method for selecting scientists in the control group is similar to that used by Borjas and Doran (2015), whose comparison group comprised excellent scientists who had received major mathematics awards. Our study also consistently observed significant differences with respect to research influence between scientists with NMS and scientists without NMS. However, NMS recipients had more research influence than did non-NMS recipients. This implies that the NMS is a better indicator of whether a scientist is influential relative to the AAAS fellowship. Because scientists who receive highly prestigious awards have better research performance, awards have been used as an indicator of research performance (Lee et al. 2019). In addition, we observed that most NMS winners obtained many other prestigious awards such as the Nobel Prize and Albert Lasker Basic Medical Research Award. By contrast, 23 non-NMS winners were awarded a lower average number of prestigious awards relative to NMS recipients. Scientists who had higher research influence and other forms of influence, such as social and economic influence, have greater opportunity to be recognized by award organizations according to the assessment criteria of distinguished scientific awards.

Although research influence and scientific contribution have been matters of concern, studies on research influence have not clearly defined the concept. Although we could not determine a clear relationship between research influence and scientific contribution, our study demonstrated that research productivity has a weaker association with scientific contribution than research influence does. The substantial scientific contributions of notable biological scientists with NMS can be proved based on their highly cited publications. Although few publications are influential for most scientists, they have been cited a substantial number of times for a long period. Therefore, the average citation per publication is not an appropriate indicator for identifying excellent scientists. Various types of research productivity and research influence cannot indicate a positive association between research performances and awards for each scientist. To enhance the precision of examining research performance, books and citations received for books must also be added to the measurements.

In conclusion, this study demonstrated the research performance of 50 biological scientists who had received the AAAS fellowship and NMS. Changes in annual research productivity and research influence among individual scientists with substantial scientific contributions and in categorizations of research productivity and research influence during three periods were monitored and compared. The influence of time on the research performance of individual scientists was reduced through the use of longitudinal data related to research performance throughout their entire academic career. Research performance at various stages of scientists' academic careers was recorded. The time frame of data analyzed in this study is greater than that used in previous studies (Borjas and Doran 2015; Chan et al. 2014; Erfanmanesh and Moghiseh 2019; Liu et al. 2018; O'Connell and Rugman 2013; Slutsky and Aytac 2018). Although scientific contribution does not entirely represent research performance in terms of numbers of publications and citations received, the present study addresses the gap between scientific contribution and research performance, which few other empirical studies have done. In particular, this study differs from previous studies in that it emphasizes interindividual differences in the research performance of prestigious award recipients. Various categories of research productivity and research influence were identified. Considerable interindividual differences in research performance only influenced the results for research performance at the aggregate level. In addition, no aggregate or statistically significant differences were identified between groups of 50 NMS winners with respect to scientists' age and *h*-index. We further compared the research performance of NMS recipients with that of scientists in the control group to examine whether the receipt of prestigious awards can serve as an indicator for distinguishing scientists according to their research performance. In line with relevant research, the present study supports that scientist recipients of prestigious awards have better research performance than nonrecipients (Borjas and Doran 2015; Chan et al. 2014; Erfanmanesh and Moghiseh

2019; Liu et al. 2018). This implies that the receipt of awards can indeed be used as an indicator of research performance. However, differences in the research performance of recipients of awards of different levels of prestige require further exploration because of the large number and diverse characteristics of NMS nonrecipients.

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References

Abramo, G., D'angelo, C., & Solazzi., M. (2011). The relationship between scientists' research performance and the degree of internalization of their research. *Scientometrics, 86*(3), 629–643.

Aksnes, D. W., & Rip, A. (2009). Researchers' perceptions of citations. *Research Policy, 38,* 895–905.

Borjas, G. J., & Doran, K. (2015). Prizes and productivity: How winning the fields medal affects scientific output. *Journal of Human Resources, 50*(3), 728–758.

Bourke, P., & Butler, L. (1996). Publication types, citation rates and evaluation. *Scientometrics, 37*(3), 473–494.

Chan, H. F., Frey, B. S., Gallus, J., & Torgler, B. (2014). Academic honors and performance. *Labour Economics, 31,* 188–204.

de Arenas, J. L., & Arenas, J. V. M. (1999). Profile of the Mexican health science elite: A bibliometric analysis of research performance. *Scientometrics, 46*(3), 539–547.

de Arenas, J. L., Arenas, M., Márquez, S., & Pérez, C. (2008). An insight into the Matthew effect in Mexico. *Library Review, 57*(5), 386–391.

Erfanmanesh, M., & Moghiseh, Z. (2019). How winning an international scientific award affects publishing behavior of laureates: The case of Derek de Solla Price Medal in scientometrics. *Publishing Research Quarterly, 35*(2), 201–212.

Greehalgh, T., Raftery, J., Hanney, S., & Glover, M. (2016). Research impact: A narrative review. *BMC Medicine*. https://doi.org/10.1186/s12916-016-0620-8.

Hirsch, J. E. (2005). An index to quantify an individual's scientific research output. *Proceeding of the National Academy of Sciences of the United States of America, 102*(46), 16569–16572.

Lee, D. J., Mutya, K., Herbert, B. E., & Mejia, E. V. (2019). Exploring scholarly impact metrics in receipt of highly prestigious awards. *Lecture Notes in Computer Science, 11420,* 147–153.

Liu, X., Yu, M., Chen, D. Z., & Huang, M. H. (2018). Tracking research performance before and after receiving the Cheung Kong Scholars award: A case study of recipients in 2005. *Research Evaluation, 27*(4), 367–379.

Mutz, R., Bornmann, L., & Daniel, H. D. (2013). Types of research output profiles: A multilevel latent class analysis of the Austrian Science Fund's final project report data. *Research Evaluation, 22*(2), 118–133.

National Science Foundation. (2018). *Nomination information*. Retrieved April 7, 2019 from: https://www.nsf.gov/od/nms/nominations.jsp.

O'Connell, D., & Rugman, A. (2013). The research productivity of the AIB Farmer Award finalists. *Multinaitonal Business Review, 21*(4), 298–311.

Perlin, M. S., Santos, A. A. P., Imasato, T., Borenstein, D., & Da Silva, S. (2017). The Brazilian scientific output published in journals: A study based on a large CV database. *Journal of Informetrics, 11*(1), 18–31.

Slutsky, B., & Aytac, S. (2018). Nobel, Priestley, and Perkin Medal winners in chemistry: Their publication productivity for the years 1992–2016. *Science and Technology Libraries, 37*(2), 211–220.

Yair, G., Gueta, N., & Davidovitch, N. (2017). The law of limited excellence: Publication productivity of Israel Prize laureates in the life and exact sciences. *Scientometrics, 113*(1), 299–311.

Zheng, J., & Liu, N. (2015). Mapping of import international academic awards. *Scientometrics, 104*(3), 763–791.