Bibliometric Analyses of Physical and Occupational Therapy Faculty across Canada Indicate Productivity and Impact of Rehabilitation Research

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ABSTRACT

Purpose: This study examines physical and occupational therapy faculty across Canada, using bibliometrics and federal funding as indicators of academic impact, and considers the validity of various bibliometric indices. **Methods:** Faculty members were identified and their rank, professional designation, and department obtained from faculty Web sites. Bibliometric indicators were determined using Publish or Perish software. An independent author (not a faculty member) inspected the data to remove any incorrectly attributed publications. The h-index, citation years, g-index, and total number of citations for each faculty member were retrieved. The Canadian Institutes of Health Research (CIHR) funding database was used to determine the amount of research funding provided to each faculty member as a principal investigator (PI) and his or her total CIHR funding received. Mean faculty indicators by university, rank, gender, and profession were determined. Analysis of variance (ANOVA) was used to detect differences by rank and gender, and measures of association (Pearson correlation coefficients and multiple regression) were used to identify factors that affected h-index and PI funding received. **Results:** A total of 347 physical and occupational therapy faculty were identified. The median h-index was 5 (inter-quartile range [IQR] 2–8) for assistant professors, 11 (IQR 7–15) for associate professors, and 18 (IQR 12–26) for full professors. ANOVA indicated no significant differences between male and female faculty in terms of h-index or funding received. Regression analysis indicated that 58% of h-index variance could be explained by gender ($p = 0.039$), appointment within a department that provides a (rehabilitation science) PhD programme ($p < 0.001$), rank ($p < 0.001$), CIHR PI funding ($p = 0.001$), or total CIHR funding ($p < 0.001$). Significant predictors of the amount of CIHR funding received as a PI included h-index ($p < 0.001$) and total number of citations ($p = 0.023$), which together explained 27% of the variation in funding received. **Conclusion:** The h-index, although not without flaws, provides a useful metric that indicates that physical and occupational faculty in Canada are productive scientists having a measurable impact and that this impact increases with rank and greater funding.

Key Words: bibliometrics; impact factors; occupational therapy; publications.

RÉSUMÉ

Objet : La présente étude examine le corps professoral en physiothérapie et en ergothérapie dans l'ensemble du Canada, en se servant de la bibliométrie et du financement fédéral à titre d'indicateurs de l'incidence sur le plan universitaire, et considère la validité de divers indices bibliométriques. **Méthodes :** On a choisi des membres du corps professoral et obtenu leur rang, leur titre professionnel et leur département à partir des sites Web des facultés. Les indicateurs bibliométriques ont été déterminés grâce au logiciel *Publish or Perish* (publier ou périr). Un auteur indépendant (qui n'est pas membre du corps professoral) a examiné les données afin de supprimer les publications incorrectement attribuées. L'indice h, les années des citations, l'indice g et le nombre total de citations pour chaque membre du corps professoral ont été récupérés. La base de données de financement des Instituts de recherche en santé du Canada (IRSC) a servi à déterminer la somme du financement de recherche attribuée à chaque professeur à titre de chercheur principal, de même que le total du financement reçu des IRSC. Les indicateurs moyens du corps professoral ont été déterminés par université, rang, sexe et profession. ANOVA a servi à repérer les différences en fonction du rang et du sexe, et les mesures d'association (Pearson et la régression multiple) ont servi à déterminer les facteurs qui avaient une incidence sur l'indice h et le financement reçu par le chercheur principal. **Résultats :** Un total de 347 professeurs de physiothérapie et d'ergothérapie ont été dénombrés. L'indice h médian correspond à 5 (intervalle interquartile de 2 à 8) pour les professeurs adjoints, à 11 (intervalle interquartile 10 à 13) pour les professeurs agrégés, et à 18 (intervalle interquartile de 12 à 26) pour les professeurs titulaires. ANOVA n'a pas permis de relever des différences significatives entre les membres féminins et les membres masculins du corps professoral pour ce qui est de l'indice h ou du financement reçu. L'analyse de régression a indiqué que 58% de l'écart de l'indice h pourrait être attribuable au sexe ($p = 0,039$), à la nomination au sein d'un département qui offre un programme de doctorat (en sciences de la réadaptation) ($p < 0,001$), au rang ($p < 0,001$), au financement des IRSC accordé au chercheur principal ($p = 0,001$), ou au financement total des IRSC ($p < 0,001$). Les prédicteurs importants de la quantité de financement reçu

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des IRSC à titre de chercheur principal étaient notamment l'indice h ($p < 0,001$) et le nombre total de citations ($p = 0,023$), qui expliquaient ensemble 27% de l'écart dans le financement reçu. **Conclusion :** L'indice h , bien qu'il ne soit pas sans défaut, constitue un paramètre utile qui indique que les membres du corps professoral en physiothérapie et en ergothérapie au Canada sont des scientifiques productifs qui ont une incidence mesurable, et que cette incidence s'accroît en fonction du rang et du financement.

The research enterprise that provides a scientific foundation for physical and occupational therapy (PT and OT) ranges from individual research studies that advance the foundational sciences to high-quality clinical studies and syntheses that support clinical decision making. Disseminating research findings through scientific publication allows others to find and apply this new knowledge. Subsequent citation of these publications is one indication that the research has been used by others, whether in practice or to advance the next stage of research. Researchers' publication productivity, citation metrics, and overall impact are of interest to those who fund health research, including funding agencies and the public. Those directly involved in the research enterprise, such as scientists and academic institutions, also need indicators of scientific productivity that can contribute to performance and impact evaluation. The phrase *publish or perish* is sometimes used to convey the importance of publication in academic institutions.

Publication metrics such as publishing in higher impact journals or citation counts are sometimes used to evaluate researchers as part of hiring, promotion, or funding decisions. Publication metrics are also used to evaluate research institutions, journals, and the impact of funding policies. Because these are high-stakes decisions, researchers are often concerned about the equity or appropriateness of metrics used to evaluate their performance. Researchers in PT and OT may face criticisms that their research does not appear in high-impact journals because most rehabilitation journals do not have a high journal impact factor (IF). Journal IFs are strongly influenced by the size of the field; thus, smaller professions or specialty journals are unlikely to rate highly. Comparing scientists' productivity or impact on the basis of the journals in which they publish is likely to disadvantage scientists from smaller fields, and such comparisons are now recognized as inappropriate.^{1,2} In fact, high-quality clinical trials in physiotherapy commonly appear in lower impact journals.³ The Canadian Institutes of Health Research (CIHR) instructs reviewers to consider the impact of the work itself rather than that of the journal in which it appears.⁴

One way of judging scientists' productivity is simply to count their publications in peer-reviewed journals because these represent a standard determined by peer review. However, not all published research makes an impact because not all published research is relevant or of high quality. The assumption that peer review ensures a high standard has been undermined with the proliferation of "predatory journals" that abuse the open-access philosophy for profit by performing perfunctory or sham

reviews. Thus, one cannot be assured that publication in a peer-reviewed journal is a sufficient benchmark of quality or impact. Several indices have been proposed that focus on the number of times a research publication is cited in subsequent publications because this may be a better indicator of the uptake of findings that contribute to the progression of science or practice. Typically, citations indicate that other scientists are reading and applying the published work, or at least that the researcher is building on his or her previous work.

A variety of bibliometric indices have been proposed. One of the most commonly used metrics is the h -index. This measure was first proposed in 2005 by Hirsch, who said, "A scientist has index h if h of his/her N_p papers have at least h citations each, and the other ($N_p - h$) papers have no more than h citations each."^{5(p.16569)} In other words, if an author writes one article and it is later cited by one other author, he or she has an h -index of 1. To achieve an h -index of 25, an author must publish 25 or more articles that must have been cited at least 25 times each.

The h -index is proposed to measure the impact of an individual's output rather than its volume, controlling for the effect of a small number of highly cited articles and rewarding consistent output.⁵ The advantage of the h -index is that it combines an assessment of both quantity (number of articles) and quality (impact, or citations to these articles). A scientist cannot have a high h -index without publishing a substantial number of articles, but publication alone does not increase the h -index because the articles must also be cited. In other words, a high h -index indicates sustained production of research that is judged to be relevant by the scientific community.

The h -index has demonstrated fairly robust validity in comparison to other indices. Hirsch⁶ calculated the h -index of Nobel Prize winners and found that 84% of them had an h -index of at least 30. In 2005, newly elected members of the National Academy of Sciences in physics and astronomy had a median h -index of 46.⁵ In subsequent work, Hirsch⁶ compared bibliometric indices with other productivity indicators and found that after the first 12 years of publication, the h -index was the indicator best able to predict cumulative achievement. Furthermore, a higher h -index has been associated with externally determined academic achievements such as academic awards, appointments, funding, and fellowship awards.

The h -index is not without criticism. These concerns have led to precautions on its use and proposal of alternative indices. Different metrics have been proposed to allow more weighting for heavily cited articles (e.g.,

the g-index); to correct for the “publication age” of the scientist, calculated based on the time elapsed since the date of his or her first indexed publication; or to improve comparability across disciplines.^{7,8} Despite these efforts, however, many of the alternative indices are highly correlated with the h-index and can be more difficult to compute or interpret.⁹ Because the greatest number of reports of productivity in different disciplines have been performed using the h-index, it does have the advantage of the largest pool of comparable data. A recognized limitation of the h-index is that comparisons across different professions or contexts should be made with caution.¹⁰

The impact of research extends beyond the scientific community and is reflected in changes in clinical practice, changes in policy, or patents on new inventions, none of which are measured by the h-index. Nevertheless, impact within the scientific community is an important precursor to other forms of uptake and is a criterion that can be evaluated. Faculty are often evaluated through a subjective process when progressing through tenure and promotion or having their productivity evaluated at grant adjudication. Use of bibliometric data could inform these processes because they provide a quantitative evaluation of the scientific impact of a researcher's work. Bibliometrics, when supplemented with other appropriate evidence, could provide a more objective evaluation of the performance of individual researchers, departments, and professions.

The purpose of our study was to examine the impact and academic productivity of faculty in PT and OT across Canada. A secondary purpose was to determine how rank, gender, and profession affect academic productivity, including h-index and federal funding awarded for health research.

METHODS

All data collection was performed by an independent research assistant (July 2013–August 2013) who had no academic appointment or knowledge of the faculty members involved other than the study coauthors. Faculty members were identified from PT and OT departments across Canada through departmental or faculty Web sites. These Web sites were used to identify rank, department appointment, and degree designations. Names identified from the faculty Web site were searched using Publish or Perish software (A. W. Harzing, <http://www.harzing.com/pop.htm>), which uses Google Scholar to identify citations and determine a variety of metrics.

Faculty were assigned to designations of OT or PT on the basis of their degrees and the departments in which they were listed. Researchers appointed in either of these departments who did not list professional designations or entry-level degrees indicating a professional designation were classified as rehabilitation scientists (RS). To avoid overcounting as a result of citations that may have been misattributed, each citation retrieved was examined

(full name, title, and coauthors) to ensure that it was correctly attributed to the targeted author. The following metrics were then calculated by the software: h-index, g-index, total number of citations, and total number of citation years (an indicator of the length of a research career). In addition, we searched the publicly available information in the CIHR-funded database to determine the amount of funding awarded to each investigator as a principal investigator (PI) and the total amount of funding received as either PI or co-investigator.

We calculated overall means and standard deviations for all variables and determined the h-index and CIHR PI funding mean, standard deviation, median, and interquartile range (IQR) for assistant, associate, and full professors across all participants. We then recalculated the h-index for a subset of faculty members employed by OT and PT programs offering an affiliated PhD (e.g., in rehabilitation science) to determine the extent to which this factor was associated with a higher h-index. We compared the h-index data with those reported in the literature for other professional groups. We used analysis of variance (ANOVA) to determine differences in indicators across subgroups on the basis of rank, gender, and presence or absence of a rehabilitation PhD program. After ranking the entire sample by h-index, we identified the top 10 scientists in each of the three levels of appointment and listed them by university, professional designation, and CIHR funding. The names of the individual ranks were removed, and their de-identified data are reported in the results. We determined the correlations between h-index, g-index, publication years, and CIHR funding. Then all variables were forced into a regression model to determine predictors of h-index by entering rank, citation years, gender, professional designation, and whether the program offered a PhD. A second regression model was used to determine predictors of CIHR funding as a PI. The variables entered were h-index, g-index, total citations, citation years, gender, rank, professional designation, and whether the program offered a PhD.

RESULTS

We identified and collected data on 348 faculty members. One outlier from McMaster University (h-index = 78), upon rechecking, proved to be a shared position between medicine and rehabilitation and was therefore removed from our analysis ($n = 347$). Table 1 shows sample demographics, indicating a predominance of women across all faculty ranks. As rank increased, so too did h-index, PI funding, and total funding. Detailed descriptive data are presented in Table 2. The median h-index was 5 (IQR 2–8) for assistant professors, 11 (IQR 7–15) for associate professors, and 18 (IQR 12–26) for full professors, indicating that h-index increases as rank increases (see Figure 1). We found small differences in these benchmarks when we limited our analysis to faculty from departments with a PhD program.

Table 1 Descriptive Characteristics of the Sample by Rank

Indicator	Assistant professor	Associate professor	Professor
Sex, % of academic appointment*			
Female	76	81	75
Male	24	19	25
Discipline, % of academic appointment			
OT	49	48	48
PT	50	47	50
RS	1	5	2
Discipline, % of sample*			
OT	20	16	12
PT	20	16	12
RS	0	2	1
Employed by a programme offering a PhD, % of sample*	30	28	18
No. of citations, mean (median), 95% CI	242 (145), 189–295	741 (503), 590–891	1,930 (1,357), 1,550–2,309
h-index, mean (median), 95% CI†	12 (11), 10–13	22 (21), 20–25	37 (34), 33–41
CIHR funds received as a PI, mean (median), 95% CI	174,005 (11,733), 110,562–237,449	372,988 (16,633), 245,113–500,863	785,638 (199,259), 523,261–1,048,014
Total CIHR funding received, mean (median), 95% CI	544,805 (74,983), 350,146–739,465	1,672,907 (410,544), 1,123,236–2,222,578	3,296,576 (1,745,546), 2,392,386–4,200,766

Note: Percentages may not add to 100% because of rounding.

*Academic position not specified: within position: 67% female, 33% male; across entire faculty sample: 2% PT, 1% OT; 2% employed by a program that offers a PhD.

†h-index = "A scientist has index h if h of his/her Np papers have at least h citations each, and the other (Np – h) papers have no more than h citations each."5(p.16569)

OT = occupational therapy; PT = physical therapy; RS = rehabilitation science; CIHR = Canadian Institutes of Health Research; PI = principal investigator.

Table 2 h-Index by Rank

Descriptor	Rank		
	Assistant professor	Associate professor	Professor
All OT/PT departments			
Mean score, 95% CI	6, 6–7	12, 10–13	21, 18–23
IQR	2–8	7–15	12–26
Range	0–19	0–30	2–49
Percentile			
5th	0	2	7
10th	1	5	10
25th	3	7	13
50th (median)	5	11	18
75th	9	15	27
90th	13	19	37
Faculty in OT/PT departments offering a PhD			
Mean score, 95% CI	7, 6–8	12, 11–14	22, 20–25
IQR	3–9	8–16	16–26
Percentile			
5th	0	2	7
10th	1	6	12
25th	3	8	15
50th (median)	6	12	20
75th	10	16	28
90th	15	21	39

OT = occupational therapy; PT = physical therapy; IQR = inter-quartile range.

Figure 1 The h-index mean (dark line), inter-quartile range containing 50% of faculty h-indices, and the 95% CIs. Four individuals outside of these CIs are noted by the small circles indicating their h-index and subject number.

Mean h-indices for faculty members at each institution ranged from 5.2 to 15.8. Faculty at the five most productive institutions (McMaster University, University of British Columbia, University of Alberta, University of Toronto, and McGill University) had h-indices ranging from 12.7 to 15.8 (see Table 3). Our analysis found

Table 3 Mean Productivity Indices for Physical and Occupational Therapy Faculty across Canada, Ranked by h-Index

University	No. of faculty listed on Web site	h-index*	g-index†	Mean total no. of citations	CIHR funds as PI, \$
McMaster University	35	15.8	30.0	1,940	2,460,996
University of British Columbia	25	14.8	26.3	957	2,098,526
University of Alberta	28	14.6	27.3	1,215	1,038,519
University of Toronto	41	13.3	26.1	1,046	2,138,884
McGill University	30	12.7	23.5	1,048	2,170,451
Western University	23	12.3	23.5	802	911,869
Université Laval	29	11.9	23.1	855	1,899,044
University of Ottawa	15	11.5	21.0	605	975,508
Queen's University	21	11.0	21.0	693	500,380
Université de Montréal	30	10.2	18.3	516	1,977,886
Université de Sherbrooke	19	9.7	17.2	507	583,668
Dalhousie University	23	6.2	11.7	253	603,579
University of Saskatchewan	10	6.1	12.3	267	68,041
University of Manitoba	18	5.2	11.0	206	171,157

*h-index = "A scientist has index h if h of his/her Np papers have at least h citations each, and the other (Np - h) papers have no more than h citations each."⁵

†g-index = "If [a set of articles] is ranked in decreasing order of the number of citations that they received, the g-index is the (unique) largest number such that the top g articles received (together) at least g² citations."¹¹

CIHR = Canadian Institutes of Health Research; PI = principal investigator.

Pearson correlation coefficients of more than 0.90 between h-index and either g-index or total number of citations, 0.49 between h-index and PI funding received, and 0.52 between h-index and citation years (see Table 4). ANOVA testing indicated no significant gender differences in productivity; we also found no inter-professional differences in h-index, although PT faculty had higher CIHR funding (see Table 5).

Descriptive information for other academic clinical disciplines (presented in Table A1 online) indicates high variability in scores and in the software through which citations were determined, but overall, PT and OT faculty h-indices met or exceeded those reported for other disciplines. For the top-ranked individual scientists at different levels, h-indices ranged from 34 to 49 for full professors, from 20 to 30 for associate professors, and from 15 to 19 for assistant professors (see Tables A2–A4 online). Regression analysis (see Table A5 online) showed that 58% of the variance in h-indices could be explained by gender ($p = 0.039$), presence or absence of a PhD program ($p < 0.001$), rank ($p < 0.001$), CIHR PI funding ($p = 0.001$), or total CIHR funding ($p < 0.001$); profession was less influential (ns ; $p = 0.06$). Significant predictors of the amount of CIHR PI funding received included h-index ($p < 0.001$) and total citation count ($p = 0.028$), which together explained 27% of the variation in funding received (see Table A6 online).

DISCUSSION

Our findings suggest that OT and PT faculty at universities across Canada are productive scientists and that

Table 4 Correlations between Bibliometric Indices and Funding Received

Index	h-index*	g-index†	Total citations
g-index†	0.96	—	—
Total citations	0.90	0.92	—
Total citation years	0.52	0.53	0.44
CIHR funding as a PI	0.49	0.45	0.47
Total CIHR funding	0.55	0.52	0.56

*h-index = "A scientist has index h if h of his/her Np papers have at least h citations each, and the other (Np - h) papers have no more than h citations each."⁵

†g-index = "If [a set of articles] is ranked in decreasing order of the number of citations that they received, the g-index is the (unique) largest number such that the top g articles received (together) at least g² citations."¹¹

CIHR = Canadian Institutes of Health Research; PI = principal investigator.

Table 5 Subgroup Analysis of Mean h-Index and Funding for Gender and Profession Subgroups

	Mean CIHR funding, \$		
	h-index*	As PI	Total
Male ($n = 79$)	13.7	427,980	1,671,150
Female ($n = 268$)	11.2	384,507	1,600,938
OT ($n = 166$)	10.6	219,806†	1,197,184†
PT ($n = 172$)	12.5	522,612†	1,868,716†

*h-index = "A scientist has index h if h of his/her Np papers have at least h citations each, and the other (Np - h) papers have no more than h citations each."⁵

† $p < 0.01$.

CIHR = Canadian Institutes of Health Research; PI = principal investigator;

OT = occupational therapy; PT = physical therapy.

the h-index is a useful metric, in combination with other information, to judge academic productivity and impact. The data are skewed, with some highly productive faculty influencing the average; therefore, when determining whether performance is typical, it is advisable to look at the IQR (the middle 50%), which defines a typical h-index as 2–8 for assistant professor, 7–15 for associate professor, and 12–26 for full professor ranks.

As expected, there is progression in academic outputs over time: Higher ranks are associated with higher h-indices and more CIHR funding, consistent with other fields.^{9,10,12,13} The descriptive data provide some metrics that can be used for comparison in performance evaluation. However, in clinical academic departments such as medicine, nursing, PT, and OT, some faculty may hold teaching, administrative, or clinical appointments, with less responsibility for research productivity, and others may have substantial protected research time and concomitantly higher publication expectations. These factors are typically considered in evaluating individual performance. Because practices around the distribution and classification of appointments can vary by department and by institution, appointment practices will inevitably have an impact on faculty summary h-indices reported. Although we support the use of IQR to represent a mid-range of typical activity, we also caution that this information should not be used in isolation.

Different methods of calculating h-index values and selecting faculty in sampling frames make it difficult to compare across professions. We did find substantial variability in h-indices across studies that addressed different disciplines. Studies that compared different methods for calculating bibliometric indices reported that different computational techniques contributed to the reported variations.^{14,15} Overall, however, rehabilitation faculty in Canada compare favourably with faculty in other clinical disciplines. For example, a study of more than 1,000 North American neurosurgeons using Google Scholar found median h-index values of 5 for assistant professors, 10 for associate professors, and 19 for full professors¹⁶ (vs. 11, 21, and 34, respectively, in our sample).

We investigated several factors that might influence h-index. We anticipated that rank would be a major factor and therefore analyzed data separately for different levels of academic appointment. A study evaluating more than 2,400 surgical faculty reported that rank was an important determinant of h-index,¹⁷ and similar trends have been reported in smaller studies.^{18,19} Rank is an important consideration when people are being judged for productivity. We did find that the spread of h-index increased over time, as reflected in wider IQRs and a greater spread in the top 10 lists at each rank; this suggests that it takes time to identify the top scientists. The small range of h-index values among the top 10 assistant professors suggests that substantial changes in ranked performance may occur within the next few years and that at this

career stage, it is difficult to identify leaders using h-index alone. Conversely, the ranking of more senior scientists is likely to be more stable and exhibits a wider central tendency interval or average performance, suggesting that outliers are more likely to be truly exceptional or underperformers. We did not find differences in h-index by professional group, which suggests that it is reasonable to compare PT and OT faculty in a single institution.

It has been suggested that male faculty tend to have higher productivity indices than female faculty.^{19–22} We did not find a significant difference when we compared male and female faculty members, but gender was significant in our regression model, which suggests that it does have an impact when other variables are controlled. Because PT and OT faculty tend to be predominantly female, the dynamics that influence the academic experience may be different from those in male-dominated departments. An analysis of neurosurgeons also reported no significant difference between male and female faculty with respect to h-index,²³ which indicates that gender differences are not consistently present; however, gender differences have been reported in multiple studies.^{19–22}

In the United States, studies have found that men receive more federal grant funding even after controlling for career longevity.^{20,21} Female academic physicians have shown lower research productivity relative to men, which has been proposed as an explanation for their underrepresentation among professors and departmental leaders.^{20,21} In academic otolaryngology departments, women produce less research output early in their careers, but at senior levels, their research productivity equals or exceeds that of men.²¹ This might suggest that early-career family issues influence women more than men. A study of social psychologists also found higher productivity among men but suggested that much of the difference could be accounted for by differences in career stage.²⁴

All of these studies suggest that comparisons of scientific output based on gender cannot be valid unless career stage, discipline, and academic position and rank are considered. Because women in the early stages of their careers are more likely to take parental leave, which is not accounted for in bibliometric indices such as the h-index, this may also contribute to differences. Lower h-indices for women at earlier career stages may indicate a gender–rank interaction that our study did not test. If the apparent disadvantage in productivity (as measured by h-index) that women experience early in their careers is attributable to leaves of absence, then it may be ameliorated by tenure and promotion processes that accommodate leaves of absence when calculating time. Women are also more likely to change their surname (or have hyphenated names), which may lead to a differential loss of citation capture.

Interest in whether bibliometrics predict success in obtaining federal research funding has been considerable.

PT and OT faculty are expected to engage in health-related research.^{25,26} CIHR is the federal agency responsible for granting health research funding; although some faculty may engage in social science research or basic research in natural sciences, which is funded by other federal agencies and may receive funding from other non-federal granting agencies, CIHR funding remains an important metric in health professional schools. In our data set, PT faculty had higher CIHR funding than OT faculty. OT faculty may have been more likely than PT faculty to apply to the Social Sciences and Humanities Research Council, which only recently stopped accepting grant applications that relate to health. Similarly, our data do not account for federal funding received from the Natural Sciences and Engineering Research Council; faculty who engage in biomechanical research (more likely PT faculty) may have additional federal funding from this source.

Moreover, CIHR provides publicly accessible information on funding provided to investigators and awards granted but not yet paid out. Because we used data on funding paid out, we have underrepresented the total amount of funding acquired by investigators, and our data may disadvantage those with recent large awards or long-term grants that have not yet been paid out. The relationship between h-index and grant funding success has not been reported for Canadian scientists, but a U.S. study found that among academic radiologists, having obtained at least one National Institutes of Health grant was associated with a higher h-index.²⁵ The same data suggested that having multiple or large grants, such as those for program projects, did not predict higher h-index,²⁵ but we were unable to test this association in our data.

Our study showed a moderate correlation between h-index and funding received, and h-index was the strongest predictor of grant success, which suggests that at the group level, funding is an important element in supporting the research enterprise. However, individual-level data (see Tables A2–A3 online for the top 10 associate and full professors) have indicated that there are isolated cases of scientists who are highly cited but who do not hold any grants as a PI. Some researchers may contribute to the body of knowledge by conducting secondary data analyses or may be funded outside of CIHR. For example, statisticians have been shown to have higher h-indices than qualitative researchers²⁷ but may more often take on a consultative role than act as PIs.

Bibliometrics are most useful when comparing researchers within similar research disciplines using the same method of calculation. Several different methods and data sources have been used to calculate h-index value;^{14,15,28} the most common are Google Scholar, Scopus, and Web of Science.²⁹ A study of citation metrics for 195 Nobel laureates in physiology and medicine calcu-

lated using these three data sources found no concordance between them in terms of the number of publications or citation counts;²⁹ the h-index was the most reliable bibliometric score. However, because different data sources provide different estimates,^{15,30,31} comparisons of h-indices obtained across different methodologies must be viewed with caution. One study on critical care intensivists found that average h-index values from Google Scholar were almost 30% higher than those obtained from Web of Science and about 15% higher than those determined by Scopus.¹⁴ It is reassuring, though, that there were no substantial changes in rankings across data sources. Cabezas-Clavijo and Delgado-López-Cózar concluded that Google Scholar is a valid tool for researchers in health sciences—both for information retrieval and for computing bibliometric indicators.¹⁴

There is considerable discussion in the literature about the benefits and flaws of different databases and algorithms. Advantages of Google Scholar are that it is freely accessible, whereas other options require substantial fees paid by academic institutions.³² Google Scholar also relies on proprietary search algorithms that appear to be more sensitive to book chapters, theses, and conference proceedings, which may partially explain why h-index values calculated through Google Scholar can be higher for some fields. It is unlikely that citations to theses and conference proceedings will influence anyone's h-index because few will be cited to any great extent. However, chapters can be important academic outputs, particularly in the social sciences. Some have argued that this is an advantage for Google Scholar because the Web of Science general search function only includes citations published in ISI-listed journals.³² This may be particularly true for rehabilitation researchers because several of their journals may be missed by the ISI data set. Google Scholar has a different aggregation mechanism than Web of Science and may be better able to manage “duplicate” publications (e.g., those with small typographical errors).

Despite its apparent potential advantages, however, there is also substantial criticism of Google Scholar. One concern is that its parsing algorithm is proprietary, which makes its accuracy difficult to check. Others have noted that Google Scholar is more likely to pick up non-academic publications that have not been peer reviewed; however, although this might contribute to publication counts, it is unlikely to have a substantial impact on citations because few researchers would cite these sources. There are differences in indices obtained through Google Scholar directly or with additional software. Google Scholar provides an h-index and an i10 index (another citation metric) and also reports “recent” versions of the h-index and i10 index that are calculated on the basis of the past 5 years. Publish or Perish software, which we used in this study, is based on data retrieved through

Google Scholar but provides more detailed bibliographic analysis, including several bibliographic indices not reported in this article.

Regardless of the method used to determine citation metrics, there is always a possibility of over- or underestimating actual citation practices.³³ Overestimation is most likely when an author's name is similar to that of another scientist and the author gets credit for the other's publications. We attempted to avoid this by individually examining each citation abstract to make sure it was properly attributed to the author.

Underestimation is more difficult to assess. Meho and Yang³⁰ found that Google Scholar missed 40% of citations obtained by using both Scopus and Web of Science, and this combination missed 60% of citations found by Google Scholar, indicating that both approaches miss citations. Google Scholar seems particularly at risk of missing older articles that may not be available online but that do appear in long-standing academic databases. Not all error is random; for example, people who change their names, use hyphenated or compound surnames, or have symbols or accented characters in their names are less likely to be identified correctly.

There are also some processes that could have affected our estimates. We relied on university and departmental Web sites to identify faculty and rank because we did not have direct access to employee files. We therefore could not distinguish tenured from untenured faculty or teaching appointments from traditional appointments, and some of the information may have been outdated. It is possible that we underestimated productivity for some faculty because of name changes or names that do not parse well. Researchers should be alert to these challenges when calculating their personal h-index because searching different name variants may be necessary. All of these factors may have affected our estimates for some researchers. Identifying faculty by Web sites, as is routinely done in bibliometric studies, is a reasonable but imperfect approach.³⁴

Bibliometric analysis is an emerging area of research, and better understanding of the h-index and similar indices may motivate improvements in how they are calculated. Despite limitations, the value of these bibliometrics as one component of evaluating performance should not be underestimated. Scientists should be aware of the extent to which the work they are producing is being cited; they should compare their productivity with that of others in their department or rank and be aware of the benchmarks they want to attain. Feedback on performance is valuable to evaluation and quality improvement in academic productivity. Quantitative evidence can be particularly useful at the time of tenure review because conflicts over productivity are better addressed with data than by relying primarily on subjective processes.

Overall, our results suggest that PT and OT faculty across Canada are productive scientists when compared with clinical academic faculty in other fields. Highly accomplished faculty are distributed across PT and OT programs in Canada. Comparison bibliometric data provided can be used to assess individual faculty productivity but should consider rank, leaves of absence, and time allocated to research to be a more valid comparison. Moreover, comparisons should be made using a similar Google Scholar-based strategy to retain comparability. An h-index is useful to measure scientific output and impact but should not be considered in isolation.

KEY MESSAGES

What is already known on this topic

The h-index indicates productivity of scientists.

What this study adds

PT and OT faculty across Canada are making a substantial scientific impact, and individual researchers should compare their h-index with group-level data from others in the same field and at the same appointment rank. Federal research funding is moderately associated with higher impact.

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