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The Graying of Academia
Will It Reduce Scientific Productivity?

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The Graying of Academia

Will It Reduce Scientific Productivity?

Wolfgang Stroebe
Utrecht University

The belief that science is a young person's game and that only young scientists can be productive and publish high-quality research is still widely shared by university administrators and members of the scientific community. Since the average age of university faculties is increasing not only in the United States but also in Europe, the question arises as to whether this belief is correct. If it were valid, the abolition of compulsory retirement in the United States and some parts of Canada would lower the productivity of these university systems. To address this question, this article reviews research on the association of age and scientific productivity conducted during the last four decades in North America and Europe. Whereas early research typically showed a decline in productivity after the ages of 40 to 45 years, this decline has been absent in more recent studies. Explanations for this change are discussed.

Keywords: academic productivity, scientific achievement, age discrimination, creative potential

The freedom to continue working until a ripe old age is a privilege that most European academics envy, because in Europe, university professors face compulsory retirement at age 65 (sometimes age 67). But even in the United States, the situation has not always been as favorable to older academics as it is now. It is only since 1994 that mandatory retirement has been abolished at universities and colleges in the United States.[1] Before then, academics had to retire at age 65 unless they were invited to stay on, an exemption typically only granted to the more eminent researchers (Roe, 1965). It was the second amendment to the Age Discrimination in Employment Act of 1967 (ADEA), passed in 1986, that prohibited mandatory retirement. But at that time, colleges and universities were granted an exemption to the law until 1994, because they argued that mandatory retirement was needed to maintain a steady inflow of young faculty and promote the hiring of women and minorities (Ashenfelter & Card, 2002; Clark & Ghent, 2008).

This change resulted in a drop in retirements of older academics and has already altered the age structure at U.S. universities (Ashenfelter & Card, 2002; Clark & Ghent, 2008). On the basis of data obtained from 16,000 older faculty members at 104 colleges and universities across the United States, Ashenfelter and Card (2002) concluded that after the abolition of mandatory retirement, the percentage of 70-year-old professors continuing to work increased from 10% to 40%. In an analysis of data from the North Carolina university system, Clark and Ghent (2008) drew a similar conclusion:

> Prior to 1994, the retirement rate was 59 percent for faculty age 70, 67 percent for faculty age 71 and 100 percent for faculty age 72. After the policy of mandatory retirement was removed, 24 percent of faculty age 70, 19 percent of faculty age 71, and 17 percent of faculty age 72 retired. (pp. 156–157)

As a result of such changes, the percentage of full-time faculty members age 70 or older went up threefold (to 2.1%) between the years 1995 and 2006 (Bombardieri, 2006). However, at some universities the situation is more extreme. For example, in the Harvard University Faculty of Arts and Sciences, the percentage of tenured professors age 70 years and older has increased from 0% in 1992 to 9.1% in 2006 (Bombardieri, 2006). The impact of the changing age structure has also been felt at the National Institutes of Health (NIH), where the average age of principal investigators for NIH grants has increased from 30–40 years in 1980 to 48 years in 2007. The prediction is that by 2020, the curve will shift even further, with a solid band of scientists spread between the ages of 42 and 66 and a tail consisting of scientists even stretching into their 70s (Holden, 2008).

Many colleges and universities try to address this issue by introducing early retirement incentive programs to motivate elderly academics to leave (Kim, 2003). Part of the justification for these programs is the aim to create opportunities for promising young academics so that they will be able to take over from their older colleagues, once those colleagues retire. However, there can be little doubt that these programs are also motivated by the belief that older researchers are less likely to produce innovative research. Thus, Clark and Ghent (2008) concluded from

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Correspondence concerning this article should be addressed to Wolfgang Stroebe, Department of Social and Organizational Psychology, Utrecht University, P.O. Box 80.140, 3508TC Utrecht, The Netherlands. E-mail: w.stroebe@uu.nl

[1] In Canada, the province of Quebec had already abolished mandatory retirement in the 1980s, and the province of Ontario followed suit two years ago.

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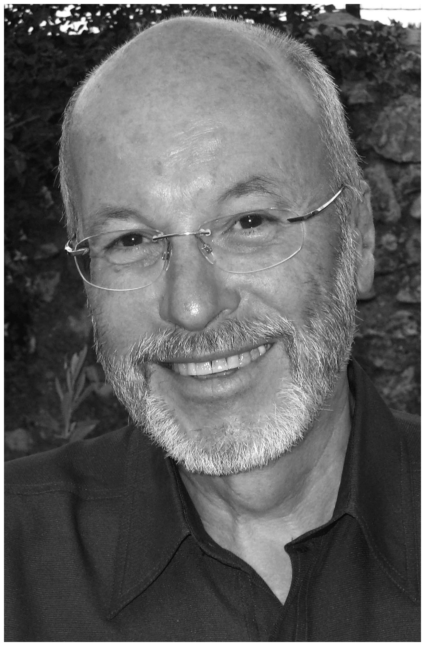

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their analysis that the decline in the ability of the North Carolina university system to hire new faculty will "alter the education and research quality of its institutions" (p. 162). Nobel laureate for economics Gary Becker (2008) expressed this fear more explicitly in a blog written jointly with Richard Posner. Commenting on the changing age distribution at American universities as a result of the abolition of compulsory retirement, Becker (2008) argued,

> Important new ideas in different fields come disproportionally from younger persons, and academic research is no exception. Significant advances not only in mathematics, but also in biology (such as Crick and Watson), in economics, and even in the humanities have typically been made by younger rather than older persons.

Becker's (2008) belief that innovative science is a young person's game has been expressed by other Nobel laureates before him. According to Albert Einstein, "A person who has not yet made his great contribution to science before the age of thirty will never do so" (quoted in Brodetsky 1942, p. 699). His fellow theoretical physicist, Paul Dirac, who like Einstein published his Nobel Prize–winning research by age 26, even turned poetic and rhymed,

> Age is, of course, a fever chill
> That every physicist must fear.
> He's better dead than living still
> When once he's past his thirtieth year.
> (quoted in Zuckerman, 1977, p. 164)

The director of the NIH, Elias Zerhouni, also expressed concern about the increase in the average age of principal investigators of NIH grants and planned to address this problem by targeting more awards to young investigators (Holden, 2008). Thomas Kelly, the director of the Sloane-Kettering Institute in New York City, shares these concerns and fears "long term implications for American science" (Holden, 2008, p. 391). Since the increase in the average age of principal investigators is likely to be a mere reflection of the increase in the average age of researchers at research universities (and perhaps of the fact that more experienced investigators write better grant proposals), it is unclear why it should be considered such a problem. There may be other reasons for instituting positive discrimination in favor of junior researchers (e.g., ensuring a pipeline), but given that the main task of these institutions is the selection and facilitation of high-quality research, one does suspect that these concerns are at least partly fueled by the belief that younger researchers would be more likely to conduct innovative research. This belief is certainly held by the leaders of the Netherlands Organization for Research (NWO), who earmarked the major part of their budget in the social sciences to grants for young scientists.

In this article, I address the question of whether there is empirical support for the belief that age is negatively related to scientific achievement. Not only is this question theoretically interesting, it is also of practical importance. If this assumption is correct, the difference in retirement practices between Europe and the United States should ultimately result in a change in the relative competitiveness of the two university systems. If it is incorrect, the opposite should be true, with valuable resources being wasted at European universities as a result of compulsory retirement. Furthermore, the fact that the belief in a negative association of age with academic achievement is still widely held in the United States and seems to have a pervasive influence on funding and personnel decisions means that the abolition of compulsory retirement did not fully succeed in eliminating age discrimination in this country. My discussion of the association of age and scientific achievement is divided into two parts. In the first part of this article, I present an analysis of potential reasons for an association of age and scientific achievement. In the second part, I then review empirical evidence from studies of the actual association between age and scientific achievement.

Age and Scientific Achievement: Potential Determinants of an Association

There are four factors that can result in age-related changes in scientific achievement, the first three being changes in the cognitive abilities required to conduct top-level research, changes in the motivation to invest time in research rather than in alternative activities, and changes in the availability of resources (i.e., funding or working conditions) needed to conduct top-level research. The fourth factor, which affects both motivation and resources, is the legal curtailing of a researcher's career through compulsory retirement.

Age and Cognitive Ability

It is puzzling that among the 16 potential causes for the decline in scientific productivity that Lehman (1953) listed in his classic monograph "Age and Achievement," the possibility of age-related decline in cognitive abilities was not mentioned, even though it was believed at the time that intellectual abilities deteriorated significantly after age 60. This belief had been based on findings of cross-sectional studies (e.g., Doppelt & Wallace, 1955; Schaie, 1958). Only later did longitudinal research demonstrate that a large proportion of this apparent decline was due to cohort differences and furthermore that not all cognitive functions declined at the same rate. Intelligence tests that allowed a distinction between *crystallized* and *fluid* intelligence (Horn & Cattell, 1967) demonstrated that the two types of abilities declined at different rates. Crystallized intelligence, which reflects mainly learned abilities (e.g., reading, writing, language comprehension), decreased much more slowly than fluid intelligence (e.g., Schaie, 1994). Fluid intelligence is assumed to reflect the neurophysiological hardware of the brain involved in the speed and accuracy of processes such as attention, visual motor memory, and discrimination. Summarizing the findings of a major prospective study that assessed mental abilities in more than 5,000 adults over a period of 35 years, Schaie (1994) drew the following conclusions:

> The longitudinal data for the single markers collected over the past 35 years indicate that average age decrements in psychometric abilities cannot be reliably confirmed prior to age 60, except for word fluency, which shows a significant decline by age 53. . . . However, reliable average decrement is indeed found for all abilities by age 67. . . . This decrement is modest until the 80s are reached. . . . Even at age 81, fewer than one half of all observed individuals showed reliable decrements over the preceding seven years. (p. 308)

Thus, even though there is a general decline in all abilities in the older age groups (e.g., Giambra, Arenbert, Zonderman, Kawas, & Costa, 1995), there is great variability between individuals, and a large proportion of elderly individuals do not experience intellectual decline even at age 80. There is also evidence that training can substantially slow down the decay (e.g., Schaie & Willis, 1986), and continuing to do research should provide an optimal training of cognitive abilities. Furthermore, although creativity is moderately positively correlated with IQ up to intelligence levels that are approximately one standard deviation above the mean, the relationship becomes essentially zero for more intelligent individuals (Barron & Harrington, 1981; Feist & Barron, 2003). Thus, when IQ scores are correlated with some valid criterion of scientific distinction (e.g., number of citations), the correlations approach zero (e.g., Bayer & Folger, 1966; Cole & Cole, 1973). This makes it highly unlikely that a modest age-related decrease in intelligence should impair a scientist's ability to produce high-quality research. Similar reservations apply to measures of divergent thinking, which are considered more closely related to creativity than are traditional intelligence tests (e.g., Hennessey & Amabile, 2010). Although there is some evidence that age decrements in divergent thinking appear as early as in the 40s (e.g., McCrae, Arenberg, & Costa, 1987), age accounts for very little variance. Furthermore, I am not aware of any study that has examined the relation of divergent thinking to scientific achievement.

The most influential theory of the association of age, cognitive ability, and scientific achievement has been suggested by Simonton (e.g., 1985, 1988, 1997, 2002), undoubtedly the most important and prolific researcher in the area of the psychology of science. He developed an elegant quantitative model of the decline in creative potential, which predicts that the association between age and productivity is curvilinear and declines with career age rather than chronological age. The basic assumption of Simonton's theory is that each creator starts off with a fixed amount of initial creative potential. This creative potential consists of "concepts, ideas, images, techniques, or other cognitions that can be subjected to free variation" (Simonton, 1997, pp. 67–68). Of the possible combinations of these, only a subset are sufficiently promising to justify further elaboration. Some of them may fail the empirical test, but some may finally be worked out into finished products that might be published. Each time individuals produce new research, they use up part of their creative potential and reduce the ideational combinations that are available to them. According to Simonton (1997), productivity increases during the first 20 years of an individual's career, when the individual still has a rich fund of creative potential and is getting better and better at turning these ideas into publishable output. However, approximately 20 years into an individual's career, a peak is typically reached. After that, productivity begins to decline, because the individual has used up a substantial proportion of his or her initial creative potential.

Although Simonton's (1997) model has been highly successful in generating valid predictions regarding the quantitative relationship of age and scientific productivity, one can question whether it is equally valid as a theory of the scientific process. One problem concerns his assumption of a fixed creative potential. There can be no doubt that there are vast individual differences in people's scientific output. But psychologists have typically attributed such differences to differences in knowledge, skills, or creative ability, which enable researchers to do research. I know of no psychological theory that assumes that in conducting research, individuals deplete their knowledge, skills, or ability. But according to Simonton, it is probably not a matter of knowledge that is being depleted but rather that its implications are being exhausted. In line with this assumption, Rietzschel, Nijstad, and Stroebe (2010) recently suggested that scientists and artists develop thinking habits in the course of their careers, habits that limit their creativity. Because idea generation uses the knowledge that is most accessible at any given moment and because knowledge accessibility is in turn linked to habitual thinking, artists and scientists are likely to develop thinking habits that gain strength with increasing years of doing research or working as artists (Rietzschel et al., 2010). Strategies that were successful in earlier work are used again, and unsuccessful strategies are discarded. Thus the longer such researchers and artists go on, the more they become prisoners of their own ideas and the less likely they are to try something different (i.e., innovative). Although it is possible within Simonton's model that researchers recharge their creative potential, the model has to assume that the amount of recharge is small in proportion to the amount already extracted. However, if the decline according to Simonton's model is due to the fact that scientists get "stuck" in their theorizing and research practice, one could argue that this process is neither universal nor irreversible. There are numerous examples of artists changing their styles and scientists adopting new research areas.

A second limitation of Simonton's (1997) model is the absence of motivational assumptions. Like most human endeavors, conducting research is an activity for which one needs to be motivated. And motivation is likely to vary over the course of a career as well as between individuals. Economists, sociologists, and most psychologists have therefore based their explanation of changes in productivity over the scientific life cycle on assumptions about changes in motivation (e.g., Diamond, 1984; Feist, 2006; Zuckerman & Merton, 1973).

Age and Motivation

Theoretical analyses about age-related changes in motivation have suggested negative as well as positive changes. An influential model that predicts a decrease in motivation with increasing age has been formulated by the economist Diamond (1984). In his economic theory of the decline of the marginal utility of research productivity with increasing age, Diamond (1984) drew on the concept of human capital to predict changes in motivation. *Human capital* refers to the stock of knowledge and skills that enable people to perform work and to produce economic value. For the research scientist, the "work" consists of administration, lecturing, dissertation supervision, and gate-keeping activities such as refereeing. According to Diamond (1984), the human capital that increases the scientist's value in these activities is his or her professional prestige, which is reflected by the current citations of all of his or her past work. By conceptualizing human capital as prestige rather than knowledge and skills, Diamond implied that a researcher's human capital needed permanent upkeep. Unless researchers keep on publishing, their prestige in their fields will decrease. The major factor in Diamond's model that determines scientific productivity is anticipated lifetime income. Because this projected income is decreasing as individuals approach their age of retirement, their motivation to increase their human capital by investing time in conducting research and producing publications will also decrease. Thus, Diamond (1984) predicted that at the start of their careers, individuals invest heavily in building up their human capital but that toward the end of their careers, the motivation to be productive declines.

This economic analysis overestimates the importance of money as a motivator of scientific productivity. Lifetime income is not the only, perhaps not even the most important, incentive that motivates scientists to engage in research. A reputation as an eminent scientist is not only good for the ego, it is also richly rewarded by the scientific community. These rewards include invitations to deliver keynote addresses at prestigious conferences (often held in nice locations, allowing eminent scientists to become world travelers), invitations to become members of prestigious institutions, and honors such as fellowships, honorary doctorates, or even the Nobel Prize. Whereas honorary doctorates and prizes can be earned with past merits and do not require continued research activities, invitations to keynote talks are typically reserved for active researchers expected to present new research findings.

If researchers' self-definitions center on their roles as active and eminent members of their scientific community and need validation through the regard they receive from fellow scientists, their motivation to continue their research activities should not decline because their anticipated lifetime income is declining. To them, income is a side-effect of eminence, not a major incentive. Furthermore, not only are eminent scientists motivated by extrinsic rewards such as lifetime income and prestige, but they are also likely to be driven by intrinsic motivation, namely, the enjoyment of conducting and writing up research, of solving a puzzle, and of gaining new knowledge. Again, this type of motivation is unlikely to decrease over the course of a career.

I would like to emphasize, however, that there are other rewarding roles available within the university system that do not require research excellence. Academics can gain prestige by becoming superb teachers, highly esteemed by their students and skilled in teaching the large introductory classes, or by becoming powerful administrators, who as chairpersons or deans can influence the fates of even their most eminent colleagues. These are all contributions that are essential for the functioning of a university and that can be very rewarding for those academics who have the ability required for achieving success in these careers. As a reflection of the association of chronological age with a greater sense of responsibility for the common good (e.g., Sheldon, Kasser, Houser-Marko, Jones, & Turban, 2005), senior researchers might also decide to devote an increasing percentage of their time to mentoring younger faculty. This might decrease their own productivity but might well increase that of their younger colleagues.

Age and the Availability of Resources

It has been argued that the differences between scientists in research productivity are too extreme to be explained merely by differences in ability or motivation (Cole & Cole, 1973). For example, in a study of the scientific output of more than 1,000 American academic psychologists, Dennis (1954) found that the most productive 10% authored 41% of all publications, whereas the bottom 10% produced less than 1%. In fact, the top half were responsible for 90% of total output, and the bottom half, for only the remaining 10%. Similarly biased distributions have been shown for other sciences as well as for the arts and humanities (Simonton, 2002). Findings such as these led Price (1963), a historian of science, to propose Price's law. According to this law, if k is the number of researchers who have made at least one contribution to a given field, the square root of k will be responsible for half of all contributions in this field. Thus, if there are 100 contributors in a field, the top 10% will be responsible for half of the contributions to this area.[2]

To explain differences of such magnitude, sociologists have suggested the hypothesis of the accumulated advantage (Cole & Cole, 1973), which implies that, owing to a variety of reward mechanisms, productive scientists are likely to become even more productive as time goes on, whereas unproductive scientists are likely to become less productive. One of the mechanisms underlying the accumulated advantage hypothesis is that one's track record is important for getting research funding at one's own university as well as from external funding sources. Thus, eminent researchers are more likely to have their grants approved or to get funds from their own institutions than are researchers with poor publication records. Successful researchers are also more likely to get job offers from competing institutions, forcing their own universities to improve their conditions even further to prevent these researchers from leaving. Although such improvements typically involve increases in salary, they are also likely to include improvements in research facilities (space, equipment) and reductions in teaching loads.

Another mechanism, which Merton (1973) termed the *Matthew effect*, is that the publications of eminent scientists are more likely to be read (and thus cited) than are those of their less eminent colleagues. And, indeed, a recent analysis of factors contributing to citation impact in social-personality psychology found a significant (albeit weak) correlation ($r = .18$) between the eminence of the first author of an article and its citation impact (Haslam et al., 2008). Eminent researchers' publications are probably more likely to be read, because colleagues expect an important contribution from a well-known and respected researcher than from a person they have never heard of. Whether this expectation is always validated is a different issue. However, there is some suggestive evidence that citation impact is related to the quality of the research reported in a publication (e.g., Nederhof & Van Raan, 1987, 1989).

These mechanisms of the academic reward system contribute to the major consequence of the accumulated advantage hypothesis, namely, that the distribution of productivity becomes increasingly unequal as a cohort of scientists ages (e.g., Allison, Long, & Krauze, 1982; Allison & Stewart, 1974). Furthermore, the fact that the academic environment is often less rewarding for those who do not conform to the "publish or perish" norm is probably responsible for the fact that they are more likely than their highly productive colleagues to make use of early retirement programs (Kim, 2003).

The Impact of Compulsory Retirement on Motivation and Resources

Most of the studies on age and scientific productivity were conducted during a period when compulsory retirement was still the rule. It is therefore important to consider the impact of this practice on academic motivation and the ability to conduct research. Although the rights maintained by emeritus professors differ in different countries, emeriti will often be unable to continue their research programs after they have retired. For example, in the Netherlands, retired professors usually lose access to the research facilities of their university and can no longer apply for research grants. In Germany, the research facilities of emeritus professors are typically given to their successors. The emeritus will have to ask for permission to use them. Furthermore, in anticipation of retirement, professors have to stop taking on new graduate students and applying for research grants, and they cannot start major research projects from around ages 58 to 60.

Compulsory retirement also lowers the chances of older academics' being able to attract job offers, which would allow them to improve their salaries and working conditions at either their old or their new places of work. In Germany, job mobility was already difficult after age 52. Because the opportunity to move to better jobs at better universities is a major extrinsic incentive for research activities, the loss of this incentive is likely to lower motivation even years before the actual retirement date. Given these multiple effects of compulsory retirement on motivation and the availability of resources, it is surprising that research on age and scientific productivity has typically neglected the fact that any decline in scientific productivity after age 60 may not be due to fading ability but rather may be forced on researchers by a system that makes it difficult or impossible for them to continue their work.

Conclusions

There is no universal age-related decline in cognitive ability. Although Simonton (1997) predicted that researchers use up a large proportion of the creative potential they start out with after approximately two decades in their careers, the psychological processes responsible for such a decline have not been worked out. I therefore argue that to the extent that an age-related decline in scientific achievement exists, it is more likely to be due to changes in motivation or the availability of resources. One major environmental factor that could be responsible for a decline in motivation and/or a cut in resources could be the con-

[2] If one looks at the impact, rather than the mere number, of publications, the distribution becomes even more biased. Impact is typically measured in terms of the number of citations a publication receives within a given period of time. For example, a study of 299 Australian academic psychologists showed that the most productive 10% were responsible for 36% of the publications but for 60% of total citations (White & White, 1978). Similarly, in a study of 291 American academic psychologists, 10% averaged more than 50 citations per year, whereas 36% averaged two or fewer (Helmreich, Spence, Beane, Lucker, & Matthews, 1980).

straints imposed in systems that require compulsory retirement.

Age and Scientific Achievement: Empirical Evidence

Methodological Considerations

There are several ways to assess scientific productivity and scientific eminence. For example, some researchers have operationalized eminence as the achievement of important scientific breakthroughs or the receipt of important scientific awards, such as the Nobel Prize. Others have operationalized it in terms of number of citations or number of publications. In analyzing such outcomes, researchers have used either cross-sectional or longitudinal designs. These designs take slightly different forms depending on the indicator of scientific productivity or eminence that is being used. In reviewing methodological problems, I first discuss the issue of the indicators of scientific achievement that have been used and then review problems related to different research designs.

Indicators of scientific achievement. There can be no doubt that receiving the Nobel Prize is an indication of great scientific achievement. The shortcoming of this indicator is that it reflects only the absolute top of the continuum of scientists. Whereas Nobel laureates are undoubtedly great scientists, many great scientists do not get this award. In some areas, such as psychology, the award is not even available. Another problem for use of the Nobel Prize in relating scientific achievement to age is that the Nobel Committee appears to be reluctant to award the prize to the same scientist twice (Zuckerman, 1977). In the sample of 414 winners of the prize in the natural sciences (Stephan & Levin, 1993), there were only three individuals who won it twice (Madame Curie, John Bardeen, and Frederick Sanger). Thus, it is quite possible that some of the scientists who received the award for earlier work may have again conducted prize-worthy research at a later date. After all, given the evidence, to be reported below, that highly productive scientists remain highly productive throughout their careers, it seems odd that the Nobel Prize–winning research should be a one-shot achievement. An alternative explanation could be the socially induced demands that come with the prize (Zuckerman, 1977). Since the Nobel laureates in Zuckerman's sample were awarded the prize, on average, at around age 50, these social demands may have kept them from their research and greatly reduced their rates of publication for the last decades of their careers.

Instead of Nobel Prizes, Lehman (1953) selected contributions identified as important in encyclopedias, handbooks, or histories of a field as indications of high-quality work. This is a less demanding criterion but also probably a less reliable one because the evaluation of scientific achievement is left to the authors of handbooks or encyclopedias.

If one defines quality as the impact a scientist has on his or her field, the most valid single indicator of scientific achievement is probably citation count (Simonton, 2002). Like any single marker, citations are by no means a perfect indicator, since some publications are widely cited because of their usefulness (e.g., personality tests, statistics books) rather than the scientific creativity that is reflected in them. However, the validity of citation counts is indicated by the fact that they are correlated with other assessments of scientists' impact such as Nobel Prizes, other awards and honors, departmental prestige, research grants, academic rank, and peer judgments (for a review, see Bornmann & Daniel, 2008).

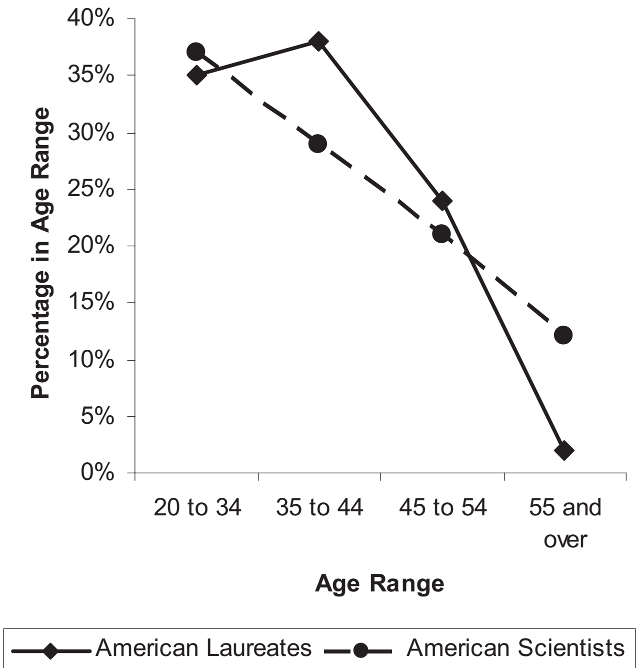
The mere number of publications, used in most of the research to be reviewed later, appears to be a much less valid indicator of scientific quality. However, there is a great deal of evidence that number of publications and number of citations are highly correlated. For example, in a study of publications by the 60 members of the editorial board of the *Journal of Counseling Psychology* in 2007, Duffy, Martin, Bryan, and Raque-Bogdan (2008) found number of publications and number of citations to correlate .80. This correlation is somewhat higher than the correlations typically found for psychology, which vary between .50 and .70 (Simonton, 2002). Simonton (2002) therefore concluded "that the quality of output is a positive function of quantity of output: the more publications one produces, the higher the odds that one will get cited" (p. 45). It is interesting to note that the same relationship has been observed in brainstorming research, where the number of ideas that are produced by an individual or a group is highly correlated with the number of good ideas (e.g., Diehl & Stroebe, 1987; Stroebe, Nijstad, & Rietzschel, 2010).

Research designs. Studies of the age at which individuals win the Nobel Prize or achieve some scientific breakthrough typically identify researchers who meet these criteria and then analyze the age distribution of these individuals. The problem with this type of analysis is that it often does not consider the age distribution of the population of scientists from which these eminent individuals were drawn (i.e., base rate fallacy). Because of the exponential growth of the scientific community during the last few centuries, there has always been an overrepresentation of younger scientists (Price, 1963). Thus, even if scientific achievement were unrelated to age, one would expect more eminent contributions from young rather than old scientists. The same bias arises with studies that use number of publications in top journals as their index of scientific achievement. For example, if one took the publications of 10 major scientific journals as one's sample and then plotted the age distribution of the authors of these publications, the results would again be distorted by the fact that there are likely to have been more younger than older scientists in the population of scientists from which the successful publishers were drawn.

This type of problem can be avoided by sampling scientists rather than publications. For example, if one analyzed the relationship of age to number of publications of members of the American Psychological Association (APA), one would have avoided the problem, because one would know the age distribution of one's population. Thus, if one would find that members ages 60 to 65 published fewer articles than their younger colleagues, this finding could not be attributed to the fact that there are fewer older than younger psychologists. However, one could still not be certain whether these differences were due to age rather than to the fact that different age cohorts have different experiences (e.g., different training; different academic socialization). One could not rule out the possibility that these older members were no more productive when they were younger than they are now. For example, because of the creation of national research institutes that took over graduate training, psychology graduate students in the Netherlands are getting much better training now than they did 20 years ago. As a result, this generation is on average likely to publish more throughout their careers than their colleagues who did their training under the old system. Similarly, because of the increased competition for academic jobs, younger cohorts might have needed more publications to succeed in getting a tenure track job (or getting tenure) than did their older colleagues.

This type of *cohort effect* can be avoided with longitudinal studies, which assess the rate of publication of a cohort of researchers throughout their life spans. However, studies that follow one cohort throughout their academic careers cannot avoid a *period effect* (i.e., the influence that changes in the historical situation might have on the cohort). For example, in the Netherlands, publication norms have become much stricter during the last two decades, and failure to conform to those norms can now result in dismissal. Thus if age were found to be positively associated with productivity in a cohort of Dutch academics, this could be due to a change in norms. Whereas the change in publication norms affects all age groups (i.e., period main effect), other historical changes affect only particular age groups and thus result in period by cohort interactions. For example, the abolition of compulsory retirement influenced mainly the age groups at both ends of the age continuum: namely, the entry level cohort, who found it more difficult to get jobs, and the oldest cohort, who found their career spans extended. The influence of such situational changes can be controlled by using cross-sequential designs, which follow cohorts who differ in age at intake, throughout their careers.

Figure 1
Age Distribution of American Nobel Laureates (1951–1972) at Time of Prize-Winning Research and of American Scientists



Note. Data are from Zuckerman (1977, Table 6-2, p. 169).

Age and the Nobel Prize

There is much anecdotal evidence that great scientific achievements are predominantly produced by the young. Newton was 24 when he began his work on universal gravitation, calculus, and the theory of colors. Gauss was only 18 when he developed the method of least squares, Bragg was a 22-year-old when he developed x-ray crystallography, and Einstein was only 26 when he published his important papers on the theory of relativity (Stephan & Levin, 1993). If the great scientific discoveries were really predominantly made by young scientists, this should be reflected in the age at which Nobel laureates conducted the research for which they received the award.

The classic study of Nobel laureates was published by Zuckerman (1977). It was based on 92 Nobel Prize winners who worked in the United States and won the Nobel Prize between 1901 and 1972. She found that the average age at which these individuals did their prize-winning research was 39 years, with winners of the prize in physics doing their research at 38.6 years and winners of the prize in medicine and physiology doing it at 41.1 years. Similar results were reported by Stephan and Levin (1993), who in an update and extension of Zuckerman's (1977) study analyzed the 414 winners of the Nobel Prize in the natural sciences in the years 1901–1992. The average age for conducting the prize-winning research for all disciplines was 37.6 years, with physicists doing their research the earliest, at 34.5 years, and medical research being conducted by somewhat older researchers, at 38.0 years.

Although this is not old, it is also not precociously young. However, before one draws any conclusions, one must remember that these findings inform us only of the proportion of Nobel Prizes won by scientists of different ages. They do not tell us at which age scientists are most likely to win that prize. For this, we need to know the age distribution of the population of scientists from which the Nobel Prize winners were selected. Although Stephan and Levin (1993) failed to make such a correction, Zuckerman (1977) did, and she compared the age distribution of her laureates to that of the general population of American scientists (see Figure 1). This comparison shows that the only substantial deviations from the general population occur for the age group of 35 to 44 years, which is clearly overrepresented among the Nobel laureates, and the age group of 55 years and older, which is underrepresented.

Before one concludes from this evidence that great science is really the domain of the middle-aged, one should remember that during the period considered in these studies, even American scientists were subject to compulsory retirement. Most research in the natural sciences requires monetary resources, personnel, and laboratory facilities, which may have become unavailable to older scientists after their retirement. In anticipation of this fact, many scientists in their mid-50s may have already stopped initiating projects that they expected to be unable to finish before retirement. Furthermore, as mentioned above, the apparent reluctance of the Nobel Committee to give the award twice to the same individual might have resulted in brilliant research not being recognized. Finally, the fact that the prize is not awarded posthumously might also curtail the age distribution (Stephan & Levin, 1993). Since there is likely to be a delay of several years between the publication of Nobel Prize–winning research and the recognition of such research as worthy of the Nobel Prize, scientists who conducted Nobel Prize–worthy research at age 55 or older might have died before their work received the kind of recognition that would have made them potential candidates for a Nobel Prize.

Age and Notable Scientific Achievements

The pattern of findings of studies that used a somewhat lesser criterion of scientific achievement is similar to that of studies of Nobel Prize winners. It is again the middle-aged researchers who are most successful, with productivity decreasing slightly in older age. It is unclear, however, to what extent this pattern is merely a reflection of the age distribution of the population of researchers from which these eminent researchers were drawn. For example, when Harvey Lehman, one of the most prolific researchers on age and scientific achievement, tabulated the ages at which a sample of 52 deceased philosophers had written their most significant work, a single-peaked function emerged: The mean age for producing a philosophical masterwork was 41.5 years. Practically the same age curve also describes the age at which significant works were produced in psychology (Lehman, 1966).

Lehman's (1953, 1966) research can be criticized for his failure to take account of the age distribution of the population of philosophers and scientists from which he drew the sample of excellent contributions. The data were not corrected for the fact that there were likely to be many more younger than older individuals in the population of which the eminent individuals were a subsample. However, Wray (2004), who studied landmark discoveries in bacteriology between 1877 and 1899, also found that scientists 36 to 45 years of age were responsible for a disproportionate number of these discoveries, even after he corrected for the likely age distribution of scientists in the total population. In contrast, younger scientists (35 years and younger) and older scientists (46 to 65 years) were relatively underrepresented.

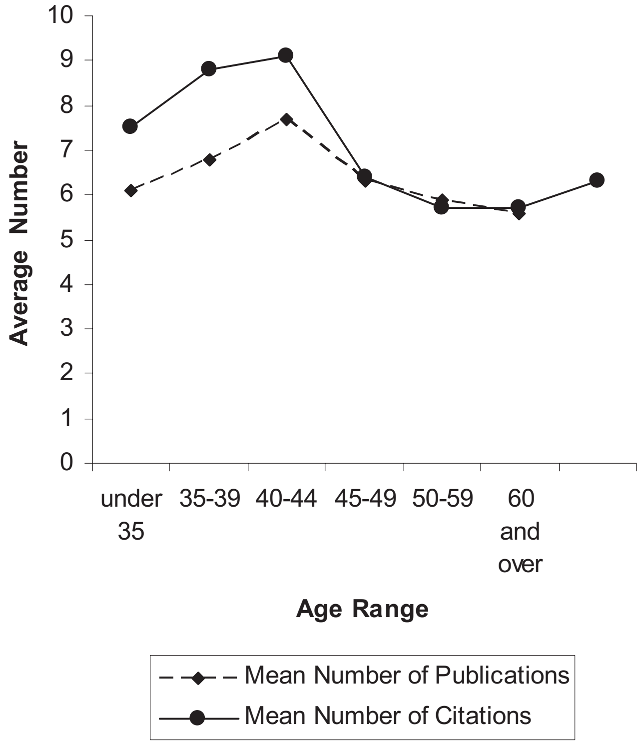
Finally, Over (1988), who used publications in *Psychological Review* as his criterion for outstanding contributions (admittedly a less demanding criterion than that of landmark discoveries, even though *Psychological Review* is one of the top journals of our discipline), found a similar curvilinear distribution that peaked for individuals who were 12 to 17 years past their PhDs (i.e., ages 38 to 45 years) and declined thereafter. However, Over (1988) argued that because 60% of American psychologists active in research between 1965 and 1980 were under 40, one could expect that about 60% of the articles appearing in *Psychological Review* in this period would be authored by psychologists under the age of 40. In fact, 59.9% of the articles in his sample were published by authors who were 0 to 11 years past their PhDs. Thus, despite the less demanding criterion, the curvilinear relationship between age and scientific achievement reported here is similar to that found in studies of Nobel laureates. However, the interpretation of these patterns depends on the assumptions made about the age distribution of the underlying population of scientists. This problem does not arise with the studies reviewed in the next section.

Age and Number of Publications

The majority of studies that analyzed the relationship between number of publications and age were conducted in the 1960s and 1970s at a time when, as noted earlier, there was much less pressure to publish in most university systems. This situation changed mostly after 1980, when clearer publication norms were established and financial rewards were more clearly tied to productivity. Furthermore, the fact that compulsory retirement was abolished in 1994 in the United States is also likely to have influenced the productivity of older academics. The following review of studies is therefore categorized into early studies published before 1990 and more recent studies published after that date.

Early studies of age and number of publications. The pattern of findings of these early studies is similar to that found in the studies of Nobel laureates and scientists with lesser achievements, with age being curvilinearly related to scientific productivity, which reaches a peak around ages 40 to 45 and then drops off (e.g., Bayer & Dutton, 1977; Cole, 1979; Dennis, 1956; Horner, Rushton, & Vernon, 1986; Kyvik, 1990; Over, 1982). This pattern was replicated in cross-sectional (Bayer & Dutton, 1977; Cole, 1979; Kyvik, 1990) and longitudinal or cross-sequential studies (Dennis, 1956; Over, 1982; Horner et al., 1986) conducted in the United States (Bayer & Dutton, 1977; Cole, 1979; Horner et al., 1986) and Europe (Dennis, 1956; Kyvik, 1990; Over, 1982). However, not all disciplines showed this pattern (Levin & Stephan, 1989). But the only discipline in which a discrepant pattern has been replicated repeatedly is mathematics. Several studies of samples of mathematicians resulted in a linear relationship, with neither an increase nor a decline in productivity (Cole, 1979; Stern, 1978).

Figure 2
Average Number of Publications Published 1965–1969 and Number of Citations by Age



Note. Adapted from "Age and Scientific Performance" by S. Cole, 1979, *American Journal of Sociology, 84,* Tables 2 and 3, pp. 962, 964. Copyright 1979 by University of Chicago Press.

Three examples of studies suffice to illustrate the typical patterns found in this research area. In one of the most extensive cross-sectional studies, Cole (1979) compared the publication rates in the years from 1965 to 1969 of 2,460 scientists from six different disciplines, including psychology. Figure 2 presents the overall productivity for the six fields combined, as well as the overall citation rate. As the figure indicates, age is curvilinearily related to both productivity and citations. Overall, the rates for productivity and citations peaked around age 40 and then dropped off. This relationship was valid for all disciplines, except for mathematics, for which the relationship was linear, "supporting the conclusion that productivity does not differ significantly with age" (Cole, 1979, p. 965). Cole thus replicated the findings of Stern (1978), who concluded from her cross-sectional study that "the notion that younger mathematicians are, as it were, 'physiologically' more able to produce papers would appear to be in error. In general, we can state categorically that age explains very little, if anything, about productivity" (p. 134).

Two cross-sequential studies of psychologists were conducted by Over (1982) and Horner et al. (1986). Over (1982) analyzed the relationship between age and productivity of a small sample of British psychologists ranging in age from 26 to 65 years. These individuals were assessed twice, once in 1968–1970 and a second time in 1978–1980. British psychologists in general published as frequently in 1978–1980 as in 1968–1970 (i.e., there was no period effect). However, both the cross-sectional and the longitudinal analyses indicated that psychologists over 45 years of age published significantly less frequently than their younger colleagues. The publication rates correlated .49 across the two times of measurement, indicating substantial stability of individual productivity. Over (1982) concluded that "a person's previous research productivity was a far better predictor of subsequent research output than age was" (p. 519).

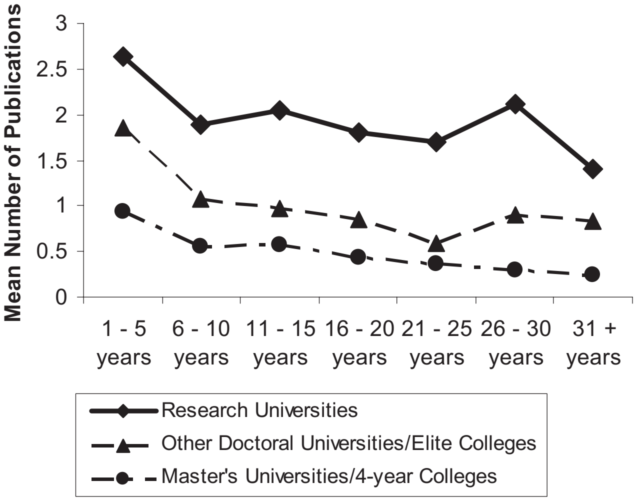
Another cross-sequential analysis on scientific productivity was based on 1,084 American academic psychologists and was conducted by Horner et al. (1986). Both the cross-sectional and the longitudinal analyses resulted in a curvilinear relationship between age and productivity. On average, the productivity at ages 35 to 44 was significantly higher than the productivity at younger and older ages. Again, the correlations between an individual's number of publications at different periods indicated a great deal of stability. Finally, age accounted on average for only 6.9% of the variance across time (more for low than for high publishers).

The findings of these early studies allow four conclusions: (a) The overwhelming majority of studies reported an age-related decline in productivity (indicated by number of articles published), and most studies found the association to be curvilinear, with a peak somewhere around the ages of 40 to 45 years. (b) Even though there was a curvilinear relationship between age and productivity, age accounted for less than 8% of the variance in productivity. In mathematics, the relationship between age and productivity even appears to be linear, with age being unrelated to productivity. (c) In contrast, past performance was by far the best predictor of future productivity. As Simonton (2002) estimated, "Between one third to two thirds of the variance in productivity in any given period may be predicted from the individual difference observed in the previous period" (p. 86). (d) Finally, even if older researchers are somewhat less productive than their younger colleagues, the quality of their work (as reflected by citations) appears to be no less high. Over (1988) correlated the number of citations each article published in *Psychological Review* had received in the first five years after publication with the age of the article's author and found that the correlation was not significantly different from zero. Similar findings were reported by Simonton (1985) in a study of the impact of the publications of 10 psychologists who had received the APA's Award for Distinguished Scientific Contributions. He found that the ratio of high-impact publications to total output fluctuated randomly throughout their careers.

Recent studies. It is probably due to the consistency of the patterns of findings on age and scientific productivity observed in the studies conducted during the second half of the last century that interest in this issue

Figure 3

Average Number of Publications per Year by Career Age at Three Homogeneous Subgroups of Institutions



Note. Adapted from "What Should I Be Doing, and Where Are They Doing It? Scholarly Productivity of Academic Psychologists" by S. Joy, 2006, *Perspectives on Psychological Science, 1,* Table 2, p. 352. Copyright 2006 by the Association for Psychological Science.

declined, and thus only four studies were conducted in recent years. This decline in the number of studies is regrettable, because the association between age and productivity in more recent studies differs from that reported in the earlier studies. Although a recent longitudinal analysis of the association of age and productivity for 112 eminent members of the U.S. National Academy of Sciences also resulted in a nonlinear relationship (Feist, 2006), this relationship was different from that reported in most earlier studies. Three unconditional growth curve models were constructed. The best fit to the data was achieved with a cubic model, providing "population estimates on productivity that increase rapidly until approximately 20 years into one's career, then flatten over the next 15 years, and then rise again over the last 5-year interval" (Feist, 2006, p. 29). Because these individuals started publishing their first articles between 22 and 25 years of age, they would have reached their first peak around age 45. After a 15-year leveling-off period, their productivity would increase again after age 60.

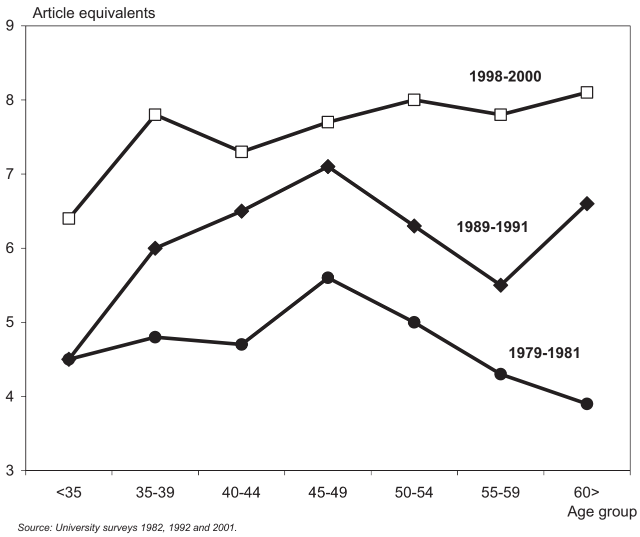
A somewhat different pattern was reported by Joy (2006), who examined the publication data of 1,216 faculty member from 96 schools ranging from elite research universities to minor undergraduate colleges. Data were collected in 2004. Figure 3 presents the mean number of publications per year by career age (i.e., years since receiving the PhD) of full-time faculty members at three homogeneous subgroups of institutions. In the context of the focus of this article, I restrict myself to discussing the data for the 399 faculty members associated with research universities (e.g., Princeton University, the University of Massachusetts at Amherst, Northeastern University). These academics published more during the first five years of their careers than in later years; their productivity remained essentially stable for the next 25 years, with perhaps a slight increase between the 26th and 30th years of their careers. Thus, the data for faculty members at research universities (or for those at other institutions) failed to show the pattern reported in earlier studies, in which productivity reached a peak around ages 40 to 45 and then dropped off (Bayer & Dutton, 1977; Cole, 1979; Dennis, 1956; Horner et al., 1986).

Productivity does appear to decline for faculty members at research universities who are more than 31 years past their PhDs and thus are age 60 or older. It is unclear whether this decline is statistically significant, because no tests were conducted, apparently because of the small number of individuals in this group. But even if the decline were reliable, it could be explained without assuming a decline in cognitive ability or motivation. Since this category includes all older full-time faculty members who received their PhDs more than 31 years ago (top age unspecified), it is likely to contain a substantial proportion of individuals who had to scale down their research activity in anticipation of their retirement. This should not have much impact for the age category of 60 to 65 years, an age when it is mainly the less active researchers who are retiring. But after age 70, when more and more of the active researchers begin to reduce their activities in anticipation of their (voluntary) retirement, there should be a marked effect on average productivity, an effect that might more than compensate for the fact that the less active researchers have already been selected out of the sample. In addition, older academics tend to write more books and book chapters (Bayer & Dutton, 1977), a category of publications that is seriously underreported by PsycINFO (Joy, 2006).[3] This trend should be particularly marked for the most active and successful researchers, because they will be most likely to receive attractive invitations to contribute book chapters or write books.

The pattern of findings of a recent large-scale cross-sectional study conducted in Quebec, a province that abolished compulsory retirement in 1980 (Gingras, Larivière, Macaluso, & Robitaille, 2008), is even more discrepant from the findings of earlier research. This study was based on 6,388 professors and researchers who had published at least one journal article over the eight-year period from 2000 to 2007. The study used 10-year age categories, ranging from age 20 to age 70. Two different sets of data were used in compiling average productivity, namely, the average productivity of all professors and that of active professors who had published at least one journal article at the age in question. Although the association between age

[3] It is interesting to note that for books, Bayer and Dutton (1977) found a straight increase in scientific productivity with career age. Since practically all studies of age and productivity focus only on articles, they are likely to underestimate the total productivity of older faculty members.

Figure 4
Average Number of Article Equivalents by Tenured Academic Staff in Norwegian Universities in the Periods 1979–1981, 1989–1991, and 1998–2000, by Age



Note. Reprinted from "Does the Aging of Tenured Academic Staff Affect the Research Performance of Universities?" by S. Kyvik and T. B. Olsen, 2008, *Scientometrics, 76,* p. 448. Copyright 2008 by Springer Science + Business Media and Akadémiai Kiadó.

and productivity was curvilinear for both samples, only the total sample showed a decline after age 50. For the active professors, productivity increased to age 50 and then stayed at the same level until age 70. (There were too few older professors to extend the study beyond age 70.) Thus, these active professors sustained their productivity at a high level throughout their careers. There was also no decline in quality for the group of active professors. In fact, the average number of articles they published in high-impact journals (i.e., the top 1% cited journals) rose steadily to age 70, and so did the average number of articles that were among the top 10% of highly cited articles.

The findings of Gingras et al. (2008) are discrepant with practically all of the early research. Given that, as noted above, the province of Quebec had already abolished compulsory retirement in 1980, this change would offer a plausible explanation for the fact that productivity did not decline for the older age group. To confirm this hypothesis, one would need recent studies conducted in the United States that showed a similar change and older studies conducted in Quebec that displayed the curvilinear pattern typical for the early studies. Even more important, however, one would also need recent longitudinal studies to rule out the alternative explanation that the pattern observed in Quebec was due to selection. There is evidence that academics with a poor publication record tend to take early retirement (Kim, 2003). The fact that publication rates did not decline with age in the cross-sectional Quebec study could therefore have been due to disproportional numbers of poor publishers taking early retirement.

However, even if the abolition of compulsory retirement motivated older academics in the Quebec study to remain productive (or unproductive academics to retire early), there must be other factors that can eliminate the age-related decline, because no decline was reported in a recent study conducted in Norway, a country that still practices compulsory retirement (Kyvik & Olsen, 2008). Kyvik and Olsen based their analysis on surveys of academic staff at Norwegian universities undertaken in 1982 (N = 1,585), 1992 (N = 1,815), and 2001 (N = 1,967). Productivity was expressed in terms of article equivalents (i.e., also including book publications). Figure 4, which presents the productivity of researchers at the three different times, reveals interesting changes in the relationship between age and productivity over time. Whereas the 1979–1981 data show the typical curvilinear pattern, the 1989–1991 data show a similar pattern with a second peak for the older age group. Finally, in the 1998–2000 data, there was virtually no difference in productivity between the different age groups, with the exception of those under 35 years of age.[4]

The general increase in productivity observed during the three time points when the survey was conducted can probably be attributed to stricter productivity norms being introduced in Norway. According to Kyvik and Olsen (2008), Norwegian universities witnessed the same increase in publication pressure as other university systems, with productivity being increasingly more rewarded in recent periods. For example, financial support for attendance at international conferences has been made dependent on paper presentations, and research funding has increasingly been made dependent on past performance. Whereas this increase in publication pressure is the likely explanation for the increase in general productivity (i.e., the period main effect), it is more difficult to see how it could specifically have affected the older age groups. One reason could be that younger academics had always been under pressure to be productive in order to ascend in the academic hierarchy. It was the full professors and those older academics who had failed to reach the rank of full professor who could lean back and relax—the latter group because they had no hope to better themselves anymore and the former group because they had already reached the

[4] This study also provides self-report information about the proportion of time academics spent on research and other activities. It seems that in 2000, younger researchers spent somewhat less of their total working time on research than did their older colleagues. This would suggest that rather than being due to the older generation's becoming more productive, the linear relationship was due to younger researchers' becoming less so. However, because even younger researchers published more in 2000 than in 1981, this can hardly be the explanation for the differences in patterns. Like universities in most countries, the Norwegian system experienced an increase in the age of tenured academic staff. Whereas in 1981 only 20% of tenured staff were older than 55 years, in 2005 this group constituted 50% of the staff. But again it is unclear how this could be responsible for the change in productivity.

zenith of their profession. With the change in the reward system (and with the increase in the number of full professors), esteem became more strongly linked to productivity than to position. For the ambitious, it was no longer good enough to be one of the many professors; one also had to be productive.

Implications and Conclusions

The findings of the research on age and scientific productivity should lessen the fears that the graying of academia will lower the international research competitiveness of the U.S. university system. Even the older studies indicated that age was only a weak predictor of scientific productivity, and this small disadvantage of older researchers may have disappeared in recent years, given that the more recent studies no longer show the typical pattern of age-related decline in research productivity. Past performance is a much better predictor of scientific productivity than is age: Researchers who are highly productive in their 30s are also likely to be much more productive in their 60s and 70s than are researchers who are not very productive at a young age. Thus, by emphasizing age over past performance, as the Dutch Research Organization is already doing and NIH appears to be considering, these institutions are replacing a strong predictor of research productivity by one that has always been weak and probably has become even less valid in recent years.

Because there have been many societal changes since the 1970s that could have moderated the relationship between age and scientific productivity, explanations of the differences in the patterns of findings observed in the early and the more recent studies have to be speculative. Three developments seem to me the most plausible causes of the recent change in the relationship between age and research productivity: namely, the abolition of compulsory retirement, the change in publication norms, and the increase in life expectancy.

The abolition of compulsory retirement in the United States and some parts of Canada is the one societal change that is likely to have had the most direct impact on the productivity of older researchers. The fact that their careers were no longer curtailed at ages 65 to 70 is likely to have increased the productivity of older researchers who had been highly productive throughout their careers. Unfortunately, longitudinal studies are needed to confirm this hypothesis, because selection effects due to (voluntary) early retirement of unproductive researchers would offer an alternative explanation for the failure of the typical age-related decline to emerge for active professors in the recent cross-sectional study conducted in Quebec (Gingras et al., 2008). However, even if the extension of their careers owing to the abolition of compulsory retirement was responsible for this finding (Gingras et al., 2008) and also explained the upturn in productivity at age 60 of the members of the National Academy of Sciences (Feist, 2006), it could not account for the change in the association between age and productivity that occurred during the two more recent decades sampled in the Norwegian study (Kyvik & Olsen, 2008).

Another factor influencing productivity has been the change in publication norms. It is the most plausible explanation for the general increase in average productivity in Norway during the three decades surveyed by Kyvik and Olsen (2008). Although European academics had to have some publications to their names if they wanted to reach the rank of full professor, in Germany (and many other European countries) this pressure to publish essentially disappeared once academics had reached this goal (e.g., Keul, Gigerenzer & Stroebe, 1993). In many European countries, the situation has changed dramatically. Universities are now being regularly evaluated in Switzerland, Great Britain, and the Netherlands, and department chairs and deans exert great pressure on staff to be productive. Although this increase in pressure is felt by everybody, it probably had a greater impact on senior rather than junior faculty. Young faculty always had to publish in order to advance in the academic hierarchy, but once they had reached their goal of becoming full professors, the pressure eased off. Now, status within the academic system is no longer associated with a particular position but with the research funds one acquires, the number of articles one publishes, the impact of these publications, and the receipt of invitations to deliver prestigious keynote addresses. Thus, even senior professors have to continue publishing if they want to be respected by their colleagues.

Whereas European universities have approached or even surpassed the publication norms that have been operating at U.S. universities for decades, it is less clear whether U.S. universities have experienced a further increase in publication pressure. In support of this hypothesis, Joy (2006) found that academics who finished their doctorates within the last five years published more as graduate students than did those with 20 or more years of postdoctoral experience. However, Lee (2000), who examined the publication records of new PhDs in experimental psychology from 1965 through 1995 failed to find a systemic change in mean number of publications from 1960 to 1990. Thus, as Joy (2006) concluded, "The status of the rising-productivity hypothesis remains uncertain" (p. 362).

The increase in life expectancy and the compression of morbidity witnessed during the last century (Stroebe, 2000) could also have contributed to the increase in research productivity of older academics. Although most of this change was due to the reduction in mortality from infectious diseases, the changes in health-impairing behavior patterns (e.g., rate of smoking; healthier diet; exercise) in response to findings of major epidemiological studies during the second half of the last century are probably more relevant. As a consequence of their healthier lifestyles, people not only live longer but also are much fitter and less vulnerable to chronic diseases than they were a few decades earlier (e.g., Stroebe, 2000). These health improvements could have prevented the decline in academic productivity that appears to have characterized older academics in 1970 and 1980.

Thus, rather than asking whether the abolition of compulsive retirement lowers the competitiveness of the American university system, one has to ask whether a rule forcing even their most productive researchers to retire at age 65 does not constitute a waste of human capital that lowers the competitiveness of university systems in Europe. If one considers (a) the financial costs to a society of training a scientist, (b) the fact that half of these individuals trained at high costs will later be relatively unproductive, and (c) that by the time these individuals reach age 60 there is more than enough information to identify the top half of the population who are responsible for 90% of publications, it seems wasteful to prevent those productive researchers from continuing to make major scientific contributions.

However, there are also disadvantages to the American system. Whereas the practice of compulsory retirement in Europe prevents even the most productive researchers from continuing their work, the abolition of compulsory retirement allows even the least productive researchers to continue. Since, due to their seniority, even unproductive researchers draw substantial salaries, having to continue employing them is a financial burden to the university system. However, because the employment of staff members of any age who fail to contribute as researchers or teachers constitutes a burden, the most desirable system would be one in which decisions on continued employment at any stage are based on individual merit.

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