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AGE AND THE NOBEL PRIZE REVISITED

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This paper analyzes the relationship between age and productivity for Nobel prize winners in science during the period 1901–1992. The relationship found is field dependent as well as dependent upon the definition used to measure the age at which the ward-winning work was done. The results suggest that although it does not require extraordinary youth to do prize-winning work, the odds decrease markedly in mid-life and fall off precipitously after age 50, particularly in chemistry and physics. The discussion underscores the problem of drawing conclusions about the age structure of research by examining medians instead of the entire distribution.

Introduction

The idea that science is a young person's game is a view to which many scientists subscribe, although few take as extreme a position as the physicist P. A. M. Dirac, who only half-jokingly stated that a physicist is "better dead than living still when once he's past his thirtieth year,"[1] (p. 164) or Albert Einstein who once said that "A person who has not made his great contribution to science before the age of thirty will never do so."[2] (p. 699). Other, less rabid believers include the Nobel laureate Abdus Salam, who stated in an interview on BBC that "there is a premium on youth"[3] (p. 20) in physics and J. Robert Oppenheimer who expressed a similar view.

There is a great deal of anecdotal evidence that science is the domain of the young. Sir Isaac Newton was 24 when he began his work on universal gravitation, calculus, and the theory of colors. Karl Gauss was only 18 when he developed the method of least squares and Sir Lawrence Bragg was a 22-year old student at Cambridge when he developed X-ray crystallography. Fred Vine was 24 and a first-year graduate student at Cambridge when he formulated what was to become known as the Vine-Matthews hypothesis, a major step toward the articulation of plate tectonics. Joshua Lederberg discovered sexual recombination in bacteria at the age of 21; Gerard 't Hooft was 25 when in 1971 he wrote an eleven-page paper that made a significant contribution to the renormalization of gauge theory.

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Anecdotal evidence, of course, does not a law make, and counterexamples exist. Max Planck was 42 when he formulated the theory of quantum energy that started the quantum revolution in physics. Wilhelm Conrad Roentgen, the first recipient of the Nobel Prize in physics, was 50 when he discovered X-rays. Carl Ferdinand Braun was 47 when he developed the cathode ray tube; Dorothy Hodgin was 59 when she solved the structure of insulin. John Bardeen, the recipient of two Nobel Prizes in physics, was 49 when he and his coresearchers formulated the BCS microscopic theory of superconductivity. Donald Cram received the Nobel Prize in chemistry for work begun when he was 49 years old on host-guest complexes. And Sir Nevil Francis Mott did most of the line of work for which he won the Nobel prize after resigning as head of Gonville and Caius College in 1963 at the age of 58.

Here we briefly explore reasons why an age-productivity relationship may exist for "elite" scientists. We then examine the age at which prize-winning work was done by the Nobel laureates in the fields of chemistry, physics and medicine from 1901 – 1992. In other work[4] which underlies the current study, we have examined the age-productivity relationship in more detail and have made a distinction between the relationship for elite scientists *vs*. "journeymen" scientists.

Before beginning the discussion, we note that age is a measure not only of the amount of time that has elapsed in a career but also the amount of time remaining in the career. This distinction proves useful in the discussion that follows. Furthermore, because we are interested in elite, as opposed to journeymen scientists, we focus on the relationship between age and creativity and the relationship between age and the willingness to spend the time required to make discoveries. We also comment on selection processes that may lead the young to appear more productive. We begin with creativity.

Age and creativity

Creativity is often associated with mental characteristics such as the ability to conceptualize, to solve problems, and to engage in unstructured and divergent forms of thinking. Creativity is also generally associated with intelligence, although high IQ is clearly not sufficient for creativity.[a] Other personality characteristics associated with creative achievement include "high valuation of aesthetic qualities in experience, broad interests, attraction to complexity, high energy, independence of judgment, autonomy, intuition, self-confidence, ability to resolve antinomies or to accommodate apparently opposite or conflicting traits in one's self-concept, and finally, a firm sense of self as 'creative'"[7] (p. 453).

Factors affecting creativity are arguably field dependent. That is, what leads to creativity in literature, poetry, or music may not lead to creativity in science. Consider, for example, the relation between psychopathology and creativity. Whereas certain types of mental illness may foster creativity in fields such as literature and art, there is no evidence that this is true in science. Indeed, the evidence reveals that creative scientists tend to be "more emotionally stable, venturesome, and self-assured than the average individual, whereas creative artists and writers tend to be less stable, less venturesome, and more guilt prone"[7] (p. 456).

Is creativity age related? One possible reason that it might be is that some of the cognitive factors associated with creativity are age related. IQ eventually declines with age,[8] although only by a small amount and only quite late in life. Some researchers describe older persons as being more cautious and more rigid in their thinking than younger persons are, as well as having greater difficulty conceptualizing and solving problems in general. Few believe that these attributes (some of which may not even be accurate descriptors of older persons) are sufficient to make creativity age related.

On the other hand, there is some support for the idea that age is related to the creative process not because of a decline in the mental processes associated with creativity but because younger persons possess a fresh point of view. They are, to use the words of the physicist Salam, "less encumbered"[3] (p. 20). They do not know about past failures and they bring a new outlook to solving a problem. *Watson*[9] suggests that Linus Pauling failed to discover the structure of DNA before Francis Crick and himself because he resisted (at the age of 50) the idea of a helical structure.

The fresh point of view of young scientists relates to the choice of the problem to be studied as well as to the processes used to solve a problem. Indeed, there is much to indicate that truly creative minds raise questions that others have not thought to ask. Many creative individuals have pointed out that the formulation of a problem is more important than its solution and that real advances come when new questions are asked or old problems are viewed from a new angle. Such certainly was the case for Newton, Freud, and Darwin.

In the nineteenth century, the psychologist *Beard*[10] elaborated a theory of why creativity might be age related. According to his theory, two elements are key to creativity: enthusiasm and experience. The former provides the motivational impetus for ideas, and the latter allows for the effective articulation of ideas. In Beard's view, the young have lots of enthusiasm but little experience, whereas the old have little enthusiasm but lots of experience. Enthusiasm without experience produces original but unfocused work, and experience without enthusiasm produces uninspired work. Thus, Beard predicted that creativity is at its zenith when the two factors cross. One appeal of this approach is that it explains why the age at which creativity peaks may be field dependent.

Beard's belief that experience may be more important in some fields than in others is loosely related to the concept of codification, used in sociology. The sociologists *Zuckerman* and *Merton*,[11] for example, define codification to be "the consolidation of empirical knowledge into succinct and interdependent theoretical formulations" (p. 507). In highly codified fields there is a strong consensus as to what constitutes the important questions and the proper approaches to solving these questions. In less codified fields there is substantially less consensus. Thus, in highly codified fields, experience may matter less because one does not need to be familiar with as many points of view. But in less codified fields, experience may be extremely important.

In this century, the psychologist *Simonton*[12, 13] has extended Beard's model. Like *Beard*, *Simonton* sees creativity as a two-tiered process. But for *Simonton* the first step is ideation, the transformation of ideas from the potential to the actual, and the second step is the elaboration of these ideas. *Simonton* posits that ideation is a decreasing function of time in the field, because in his view the longer someone has been in a field, the fewer are the potential ideas left to be ideated. Elaboration, on the other hand, depends on the number of ideas already ideated waiting to be worked out. Early in the scientist's career, ideas are transformed from the potential to the actual. In the process, the scientist builds up a stock of ideas to elaborate later on. Eventually, this stock grows smaller, and consequently the number of ideas articulated in a given period also begins to wane. Creativity has peaked.

The Simonton model can also be used to explain why the creative process may vary across fields. *Einstein*[14] knew the precise day on which, "there came to me the most fortunate thought of my life." In other fields, it takes years to articulate an idea. In these highly uncodified fields the age-creativity profile is fairly flat. The contrast between "zombie biology" and physics illustrates this point: The molecular biologist Sydney Brenner once thought of founding a journal called the *Journal of Zombie Biology*, not for the biology of zombies, but for zombie biologists. His reason: "Because that's all you have to do. You just have to wind yourself up in the morning, and go to the lab and just do things... many of the answers come from just doing things. Biology isn't a subject in which you can have great thoughts in the bath." The nuclear physicist Leo Szilard (who left physics to work in biology) once told Brenner that he could never have a comfortable bath after he left physics. "When he was a physicist he could lie in the bath and think for hours, but in biology he was always having to get up to look up another fact"[3] (p. 107).

There are other reasons why creativity may be age related. Many of these relate to the sociological concept that persons coming from the margin – "outsiders" if you will – make greater contributions than do those firmly entrenched in the system. In addition to having a fresh point of view, people from the margin have less invested in a particular idea or school of thought, and consequently they have neither status nor reputation to lose if their research fails. Thus the costs of looking at something from a different perspective are low for "marginal" persons, but the benefits may be extremely high. Because young persons are new to the field and have not accumulated a reputation, they are, in this sociological perspective; marginal and hence more likely to be creative.

Younger scientists may also be more likely to have the type of knowledge that predisposes them to making important discoveries, especially younger scientists working in highly codified fields. This is not only because their knowledge may be more up-to-date; they may also have a broader background, having recently come from graduate school in which they were required to take courses across a wide range of topics. By contrast, older scientists may possess less up-to-date knowledge (see discussion in *Stephan* and *Levin*[4]) and, due to the specialized nature of research, have a narrower research focus.

Age and selection

Youth and significant work may also go hand in hand in science because of what could be called processes of selection. For example, scientists who are extremely creative – who have what some refer to as a sacred spark – often begin to make discoveries earlier in their lives than do other scientists. That is, they have a head start precisely because of this ability. Pascal wrote a paper on conic sections at the age of 16 or 17; Galileo discovered the isochronism of the pendulum at 17; and by the age of 22 both Darwin and Einstein were publishing. (See *Simonton*,[13] p. 184 for other examples of precocious scientists.) According to *Zuckerman*,[1] American Nobel laureates in science publish on average more than a dozen papers before their thirtieth year, approximately four times as many as scientists in general contribute in an entire lifetime. Thus, a relationship between age and creativity may exist because great contributions are made by scientists with the sacred spark, and such scientists, precisely because they do have a special talent, start doing science at an earlier age than do those who are not as talented. From this it does not necessarily follow that science is a young person's game; exceptionally talented scientists may continue to be productive as they age and are joined by other, less able scientists in their age group.

A related issue is that exceptionally talented scientists not only start early but also are attracted to areas of science in which major breakthroughs are occurring (or likely to occur), for it is in these fields that research will have the highest rewards. For example, Crick and Watson chose to do research on DNA because they saw this as being an area on the cutting edge. According to the sociologist *Blau*,[15] breakthrough fields "attract the most capable young scientists, who in turn, by virtue of superior abilities and training, solve the problems in short order" (p. 204). According to this view, it is not necessarily that young talent is required to solve special problems, it is just that young talent is especially attracted to "hot" fields. After the field has been mined and the scientists are older, they may be content to do backwater or what some call ditchdigging research, rather than to retool and challenge a new frontier. The latter course, after all, is not only risky but also involves substantial costs.

Age and the willingness to do science

Scientists contribute not only cognitive resources to doing science. They also contribute effort. Although it is popular to characterize scientists as having instant insight, scientific research takes time. "Any scientist who is not willing to put in the hours formerly reserved tor factory workers in Victorian England is not likely to succeed"[16] (p. 160). *Fox*,[17] a sociologist of science, notes that "productive scientists, and eminent scientists especially, are a strongly motivated group of researchers" and have the "stamina' or the capacity to work hard and persist in the pursuit of long-range goals" (p. 287).

There are several reasons that the amount of effort scientists expend on research may be age dependent. One reason relates to what sociologists of science refer to as cumulative advantage, that is the idea that the recognition awarded to research increases with the amount of successful research that the scientist has already done. As a result "two publications of equal intrinsic merit will receive differential recognition if the authors are unequal in prestige"[18] (p. 615). Successful scientists not only accumulate advantage. They also acquire a taste for success. A reinforcement process is at work. The implications for productivity implicit in cumulative advantage and reinforcement theory are clear: For the individual, scientific productivity is correlated over time. Scientists productive in an early period are productive in later periods; those not productive at an early date are less likely to be productive at a later date. Thus, unless success comes fairly early in the career, even if the scientist is capable of doing extraordinary research, the processes of cumulative advantage and reinforcement may lead to discouragement with age and hence to the unwillingness to commit the hours required to have a successful research agenda.

Older scientists may also be unwilling to expend the vast amount of time significant contributions often require if they refocus their priorities as a result of age. A popular view is that this indeed occurs, that not only children but also adults pass through various stages as they age. Developmental psychologists see adults as going through distinct stages of development as they confront a sequence of developmental tasks. From the viewpoint of our research, of most interest is the stage of development that people report experiencing in their late thirties and early forties. This is the stage characterized by reassessment, a stage that *Levinson*[19] calls Mid-life Transition. It is a stage that *Neugarten*,[20] in a well-known study of middle aged persons, found characterized by "reflection" and "stock-taking," a stage in which people structure and restructure their experiences in light of what they have already learned (p. 139).

How does this affect scientists? What does the developmental view portend for them? One possible scenario is that the concept of giving everything for science seems rational to young scientists. But somewhere in their late thirties or early forties, scientists begin to realize that they, too, are mortal. They begin to question whether recognition is worth the extreme effort it requires. They may begin to see their legacy to future generations more in terms of administering programs and teaching classes than in doing research. *Zuckerman* and *Merton*[11] suggest that the shift from the research role to other roles is more characteristic, however, of journeymen scientists than of more accomplished scientists. They suggest that this occurs not only because the successful have accumulated advantage and acquired the taste for recognition, but also because they see this as a validation process. They must continue to work after receiving exceptional recognition such as the Nobel prize, in order to "validate the judgment that the eminent scientist has unusual capacities and to testify that these capacities have continuing potential" (p. 532). While such a view is undoubtedly correct for some eminent scientists, it ignores the fact that because of their eminence, elite scientists are often offered opportunities that the noneminent never have. Usually these come in middle age and involve administering something big, such as a university, a laboratory, or a company. Thus, at approximately the age that they may begin to reevaluate their lives and possibly the age that their creative prowess begins to decline, the eminent may have the opportunity to accept a position which involves high status but provides little time for research.

The position may not only involve high status, but also significant economic rewards. And despite the common view that scientists eschew monetary rewards, there is every indication that an interest in financial rewards is one of the motivating forces in science.[b] This interest may provide another reason why scientists are less productive as they age. As both *Diamond*[22] and *Stephan* and *Levin*[4, 23] have outlined, because of the finiteness of the career, the present value of the benefits to doing research decrease with age, while the opportunity costs of doing research may increase, especially if the scientist has been successful enough in the early stages of the career to be offered alternatives to a traditional research profile. This can lead scientists to commit less time to research as they age.

Results: the Nobels

The most obvious group of eminent scientists to study in order to examine the age-productivity question is Nobel laureates, for there is fairly wide consensus that in the three fields in science in which the prize is awarded it represents the ultimate accolade. Distributed for the first time in 1901, with but few exceptions the prize has been awarded annually in the three fields of chemistry, physics, and medicine or physiology (referred to hereafter simply as medicine). In many years, the prize is shared by two or more researchers so that by 1992, a total of 414 prizes had been given in the three fields to 412 scientists. (Madame Curie and John Bardeen were both repeat winners.)

Table 1 presents, for the period 1901–1992, the distribution of laureates by field according to the age at which they did their prize-winning research. Unlike earlier studies by *Zuckerman*[1] and *Manniche* and *Falk*[24] which report the age at which the prize-winning research was published, here we report the age at which the prize-winning research was conducted.[c] When the research occurred over a period of time, as is often the case, particularly when an award is made for a "line of research," the midpoint is reported.[d] The primary source of information was *Wasson*.[25] Additional information was obtained from periodicals such as *Physics Today, Science, Science News*, and *Scientific American*.

Table 1
Percentages of scientists in different age groups when doing Nobel Prize-winning work, 1901-1992, Mid-point definition

Age	Chemistry	Physics	Medicine	All
21–25	0.8	7.1	0.6	2.9
26–30	15.3	19.1	10.3	14.7
31–35	26.3	27.0	25.2	26.1
36–40	29.7	18.4	24.5	23.9
41–45	16.9	17.7	24.5	20.0
46–50	5.9	7.1	5.8	6.3
51–55	0.8	1.4	6.5	3.1
56–60	3.4	1.4	1.3	1.9
61–65	0.8	0.7	1.3	1.0
Mean Age	37.8	36.0	39.0	37.6
Median Age	36.8	34.5	38.0	37.0
No. of Cases	118	141	155	414

Several generalizations can be drawn from the table. First, the age distributions differ by field; the chi-square statistic used to test for differences is significant at the 5 percent level.[e] This finding is consistent with the research of others and the theoretical point of view discussed above. The Nobel laureates in physics tend to be the youngest, and those in medicine are usually the oldest. Second, although relatively few of the laureates are under 25 at the time they do their award-winning research, a significant number are in their late twenties, and even more are in their early thirties. Indeed, in physics, the largest proportion of laureates (over one quarter) do their work in their early thirties, and in chemistry, the highest proportion are in their late thirties. Furthermore, by the age of 40, nearly three-quarters of all laureates in chemistry and physics have done their research, and in all three fields by age 45 over 85 percent of the laureates have done their prize-winning work. Third, the distributions, particularly in physics and chemistry, fall off precipitously after the age of 50. Indeed, for all three fields combined, less than 3 percent of all prize-winning researchers are over 55 at the time they do their work.

As noted above, Table 1 reports the distribution using the mid-point to determine the age at which the prize-winning work was done. Because award-winning research often takes several years to complete, it is important to look at the age the prize-winning work was commenced as well as the age at which it was completed. These distributions are reported in Table 2.

Table 2
Percentages of scientists in different age groups when doing Nobel Prize-winning work, 1901 – 1992, Beginning age and ending age definition

Age	Chemistry		Physics		Medicine		All	
	Beginning age	Ending age	Beginning age	Ending age	Beginning age	Ending age	Beginning age	Ending age
21 – 25	19.5	0.0	13.5	2.8	14.2	0.6	15.5	1.2
26 – 30	30.5	5.9	29.8	12.1	27.7	3.2	29.2	7.0
31 – 35	31.4	13.6	21.3	23.4	26.5	12.3	26.1	16.4
36 – 40	7.6	18.6	18.4	17.0	16.8	25.2	14.7	20.5
41 – 45	5.9	18.6	8.5	24.1	7.8	12.9	7.5	18.4
46 – 50	1.7	19.5	6.4	11.3	3.2	20.0	3.9	16.9
51 – 55	1.7	13.6	0.7	5.7	2.6	12.9	1.7	10.6
56 – 60	0.8	5.9	1.4	2.1	0.0	3.9	0.7	3.9
61 – 65	0.8	4.2	0.0	1.4	1.3	9.0	0.7	5.1
Mean Age	31.6	43.8	33.1	39.2	33.2	44.7	32.7	42.6
Median Age	30.5	43.0	31.0	39.0	32.0	44.0	31.0	42.0
No. of Cases	118		141		155		414	

When the age distributions are presented in terms of the age at which the award-winning research was initiated, we find that over 80 percent of the chemists and approximately two-thirds of the physicists and laureates in medicine begin their prize-winning work before the age of 35. We also find that less than 8 percent of all laureates commence their work after the age of 45, and only a handful (13 out of 414) after age 50. When we focus on the distributions in terms of the age at which the prize-winning work was completed, the distribution in physics is the youngest. Indeed, in physics, we find that more than a third of all laureates had completed their prize-winning work by the age of 35, and over three fourths had completed their work a decade later at age 45, while in chemistry and medicine by age 40 about 40 percent had completed the Nobel-research and by age 50 about three-fourths had completed their prize-winning work. These differences persist with age and are a result of the fact that in physics the Nobel prize-winning work spans the shortest period of time. It is this fact, not the fact that laureates in physics start earlier, that explains why, using the mid-point definition of work (Table 1) laureates in physics tend to be the youngest. On the other hand the mid-point difference between medicine and chemistry noted above stems from the fact that the typical researcher in medicine (often a clinician) starts the award-winning research at a later age than does the chemist but takes approximately the same amount of time to complete the work.[f]

Discussion

The tables suggest that although it does not require extraordinary youth to do prize-winning work, the odds decrease markedly in mid-life. The relationship is field dependent as well as dependent upon the definition used to measure the age at which the award-winning work was done. But at the outside, it is safe to say that regardless of field, the odds of commencing research for which a Nobel prize is awarded decline dramatically after age 40 and very, very few laureates undertake prize-winning work after the age of 55.

The discussion also points out the problem of drawing conclusions about the age structure of Nobel research by examining medians instead of the entire distribution. This is because the distributions are so highly skewed to the left that very, very few observations fall in the right tail. Extreme youth does not appear to be that great a blessing, but older scientists appear extremely unlikely to do research for which a prize will be awarded.

Does this mean that one *must* be young to do great work? Obviously not. Exceptions, as noted in the introduction, clearly exist. But there are two other reasons to answer in the negative that relate to the data and study design. First, the Nobel prize is not awarded posthumously. This means that the age distribution is, without doubt, biased somewhat toward the young. Second, many productive scientists with long careers are recognized for early contributions, especially since it can take a significant amount of time for a contribution to be recognized as worthy of a prize. Here we have not studied what happens to the research careers of the scientists after they win the prize but numerous examples come to mind of laureates who made extraordinary contributions after winning the prize.[g]

More importantly, in answer to the question "Must one be young to do great work?" we should point out that *must* connotes an inevitability that clearly does not exist. As we have shown in earlier work,[4] age is but one of a complex of factors that affect productivity. It is extremely important for scientists (and public policy makers) to keep this in mind so that research such as this does not lead to the misperception that scientists cannot be exceptionally productive in the later years of their careers.

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Notes and comments

a *Albert*[5] reviews studies of the relationship between exceptionally high IQ and creativity and concludes that "more than cognitive giftedness is required for exceptional career achievement (p. 17). There is some support for the threshold theory of creativity. "According to this theory, some intelligence is necessary for creativie performance but only in the moderate and high levels of intelligence is creativity ostensibly independent. Some have gone as far as to suggest that an IQ of 120 represents the minimum IQ threshold for creativity"[6] (p. 241).

b When *Rosovsky*,[21] upon becoming dean of the Faculty of Arts and Sciences at Harvard, asked one of Harvard's most eminent scientists the source of his scientific inspiration, the reply (which "came without the slightest hesitation") was "money and flattery" (p. 242).

c Given that on average there is an 18 month lag between research and publication, the reported ages of Table 1 should be approximately 18 months younger than those reported by *Zuckerman* and *Manniche* and *Falk* for an earlier period.

d This means that there is an element of judgment as to the starting and ending dates for the "body of work" honored. Indeed, since beginning our research, correspondence with knowledgeable individuals as well as additional research has led us to revise the dates in four cases: Anderson, Cram, Mott and Lipscomb.

e Since more than one-fifth of the fitted cells had a frequency of less than 5, in order to make the significance tests not suspect the age categories were regrouped as follows: age groups 21–25 and 26–30 were collapsed into one category as were the three age groups over 51. The resulting chi-square statistic was 20.14, which, with 10 degrees of freedom, is actually significant at the 3 percent level.

f The chi-square test for differences in the distributions by beginning age is *not* statistically significant at traditional levels (15.52 with 12 degrees of freedom). The test for differences in the distributions by ending age is statistically significant at the 1 percent level (47.52 with 16 degrees of freedom).

g Bethe, Chandrasekhar, Crick, Feynman, Fowler, Gell-Mann, Landau, Luria, Onsager, and Pauling are all examples of laureates who made "post-Nobel" discoveries viewed by many to be equivalent to those for which they won the prize.