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This paper reports the results of two studies on the development of scientific talent among the scientific elite: finalists in the Westinghouse Science Competition and members of the National Academy of Sciences (NAS). Sampling four cohorts of finalists, we examined whether these gifted teenagers actually do go on to be the best scientists of the next generation by coding education and career outcomes. Finalists were quite successful and stayed mostly within science and medicine for their career choice. A rather high—although marginally unequal—portion of male (91%) and female (74%) finalists earned a doctoral degree. Women were also more likely to change to non-scientific professions than men. Among the most compelling findings from the NAS study were: age that scientific talent was recognized by self and others was an important predictor of early publication, which in turn was an important predictor of lifetime productivity. Growth curve analyses suggested a cubic model of best-fit productivity data over time. Moreover, in both samples there was an association between scientific achievement and recent immigrant status. Various theoretical models are discussed as possible explanations for the developmental, gender, and immigrant-status findings on scientific talent.

KEY WORDS: psychology of science; achievement; career outcomes; gender; immigrant status.

INTRODUCTION

The impact of science on society has never been greater than it is today. Science and technology influence just about every aspect of our lives. An important developmental question therefore is "who are our future scientists?" More importantly, "who are our best future scientists?" Are there any telltale signs early in life of later scientific interest, talent, and achievement?

The recent Third International Mathematics and Science Study-Repeat (TIMSS-R) compared math and science education performance from 38 countries (Martin et al., 2000). The good news and the bad news is that U.S. 8th grade students scored precisely at the "average" for math and science. Also compared to their American peers 4 years prior, U.S. students are doing neither worse nor better in math and science. And yet given the mediocre scores of our primary and secondary education students in math and science, there is a paradox: U.S. scientists win roughly 60% of the Nobel prizes in science and medicine and on an average are doing the best science in the world (Zuckerman, 1996). How do we explain this paradox of the U.S. going from being perfectly mediocre in high school to being the best in the world by graduate school and beyond?

The answer almost certainly has to lie in the relatively small percentage of gifted and talented young high school students who go on to flourish at the college and graduate level. The U.S., more than most of any other country, is very diverse and variable in its talent and achievement pool. Some do very poorly, many do average and a few do very, very well.

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The average covers up the extremes and therefore under estimates what the top echelon may be capable of (Berliner, 2001). It is the group that does very well which bridges the chasm between overall average high school performance and later world-class scientific achievement. In addition, of particular concern is whether the scientifically gifted women and minorities are self-selecting out of scientific careers at rates disproportional to men and European-Americans. By studying both ends of the age spectrum (the young and talented and the older world-class achievers), we can better understand the paradox of mediocre levels of achievement in high school compared with world-class achievement in adulthood and why women and certain minorities may be opting out of careers in the physical sciences.

The proposed research aimed to investigate these questions by first taking a group that is the very criterion of early scientific potential and talent, namely teenaged winners of the most prestigious and competitive science fair in the U.S. (Westinghouse), and examining whether they actually do go on to be the best scientists of the next generation. In addition, by, in essence, holding scientific talent constant (all finalists are in the extreme end of the distribution—that is, top 1%), we could examine the effect that gender might have on education, career, and reward outcomes in the highly talented young scientists. That is, even for the most gifted and talented teenagers are there gender differences in obtaining bachelors and graduate degrees in science, in staying in science, in the kind of science one pursues (physical, biological, social), in productivity (publication rates), and finally in the kinds and number of honors and awards one receives.

Secondly, one can take the very best scientists of the current generation (National Academy of Science (NAS) members) and glance backwards at their youth: did they give any consistent hints of their later talent and achievement? Since we know this group is a clearly recognized criterion of high levels of scientific achievement (J. Cole & S. Cole, 1973; Feist, 1993), examination of their career paths can shed light on a number of crucial questions concerning and scientific talent and achievement. These were the two approaches used in the current investigation. Moreover, these two studies primarily focused on the topics of age and gender in science.

Age, Giftedness and Scientific Achievement

The general topic of the development of scientific interest and achievement parses into a number of specific questions concerning when interest and talent first manifest themselves and how productivity changes over the lifespan. For instance, one commonly examined question is "Do the most prolific scientists publish earliest in life and does the peak in productivity occur around 20 years into one's career?" As we shall see, the age at which one is first productive reliably and robustly predicts lifetime productivity.

Research on whether the young and gifted go on to realize inordinately creative achievements in adulthood is equivocal. Perhaps the best-known example of a longitudinal study of creativity was Terman's gifted sample (IQ > 140) (Terman, 1925). Although the sample as a whole achieved higher than normal levels of education and career success (Holahan & Sears, 1995), if one uses standard creativity criteria (impact, productivity, and honors and awards), the Terman group in general was surprisingly uncreative over the course of their careers. Few major writers, artists, or scientists emerged from this 'genius' level IQ group. Other well-known longitudinal studies of giftedness, however, demonstrated higher levels of creative achievement in adulthood; these include Julian Stanley's Study of Mathematically Precocious Youth (SMYP; Benbow & Minor, 1986; Benbow & Stanley, 1982; Lubinski & Benbow, 1994; Stanley & Benbow, 1982) and Rena Subotnik's longitudinal examination of 1983 Westinghouse semi-finalists (Subotnik & Steiner, 1994; Subotnik, Duschl, & Selmon, 1993).

Gender, Scientific Interest and Achievement

The question of gender differences in scientific interest, motivation, and achievement also continues to be an important, if not contentious, one. Historically, research has pointed to some gender effects in interest and achievement outcomes in science (Benbow, Lubinski, Shea, & Eftekhari-Sanjani, 2000; J. Cole, 1987; J. Cole & S. Cole, 1973; J. Cole & Zuckerman, 1987; Farmer, Wardrop, & Rotella, 1999; Hedges & Nowell, 1995; National Science Foundation, 1999; O'Brien, Martinez-Pons, Kopala, 1999; Reis & Park, 2001; Subotnik et al., 1993). The general conclusion from this body of research is that although there is no overall difference in intelligence, men are more likely than women to view science positively, be more interested in science and math as a career, and to achieve at higher rates (publish).

There are, however, at least two important qualifications to these generalizations: gender differences in interests do not reliably appear until early adulthood, and they are less apparent in the social sciences than the physical sciences (with biological sciences being in the middle). For instance, in terms of courses taken, the "gender gap" in science is not evident at the high school or undergraduate level or in the social sciences (NSF, 1999). High school male and female students were equally likely to take advanced math courses (trigonometry and calculus) and almost as likely to take advanced science courses (biology, chemistry, and physics). In advanced science courses there was a slightly higher percentage of females taking biology and chemistry, and a slighter higher percentage of males taking physics. As students progress through their academic careers, there is an increasing gender disparity in interest in science and math. At the undergraduate level, the percentage of women who earned science or engineering degrees in 1995 was 46% (after being about 38% 10 years earlier; NSF, 1999). At the graduate level a more obvious gender gap exists, even in the biological and social sciences, with 39% of the masters degrees in science and engineering and 33% of the doctoral degrees in science and engineering being awarded to women (NSF, 1999; cf. Subotnik et al., 1993). And finally in terms of career, the disparity widens even more, with 4–6% of the full professors in science and math being women (Rosser, 1988). The most extreme difference between the genders is seen at the most elite level. Only about 2% of the members of the NAS are female (Rosser, 1988).

The other qualification is not all fields of science are equally gender-biased in their distributions. It is most striking in the physical sciences, less striking in the biological sciences, and least striking in the social sciences (cf. Hedges & Nowell, 1995; NSF, 1999). For instance, in 1998 only 17% of the engineering degrees and 35% of both the mathematics and physical-earth science degrees were awarded to women, whereas nearly 50% of the biological and social science degrees, and 73% of the psychology degrees were awarded to women (NSF, 1999). In addition, in a sample of mathematically precocious students who immediately after high school said they intended to major in math or science, five years later men were more likely to have received engineering and physical science degrees (effect sizes Cohen's d of .54 and .34, respectively) and women more likely to have received biological science and medical science degrees (effect sizes of −.26 and −.22, respectively) (Webb, Lubinski, & Benbow, 2002).

STUDY 1: WESTINGHOUSE SCIENCE COMPETITION FINALISTS

From 1942 until 1997, Westinghouse Corporation sponsored the largest, most selective, and most prestigious science talent search in the U.S. for high school seniors. Since 1998 Intel Corporation has been the corporate sponsor. Annually, there are 300 semifinalists and 40 finalists out of approximately 1,500 science fair participants across the country. This pool of talent, therefore, makes a perfect target group from which to examine the question of what happens to our brightest young scientists with the most potential. We targeted four different cohorts of finalists spanning 30 years (1965–1995) to provide a detailed and complex view into the unfolding of careers of the scientifically talented.

Participants

We chose to study each of the 40 finalists from four different Westinghouse cohorts, namely 1995, 1985, 1975, and 1965 ($N = 161$; 1995 had 41 finalists). These cohorts varied in mean age from 24 to 54, and overall there were 50 (31%) women and 111 men. A non-significant trend suggests that the percentage of females is increasing, going from 25% in 1965 and 1975 to 27.5% in 1985, to 46% in 1995 (χ^2 (3) = 5.97, p = .11). Against a base-rate of 77% European-Americans and 4% Asian-American (East-Asian and South-Asian) in the overall U.S. population (U.S. Census, 2002), the European-Americans were slightly over-represented (129/156 = 83%), and the Asian-Americans (24/156 = 15%) were quite a bit over-represented in the Westinghouse population. Hispanic-Latino Americans were under-represented (3% vs. 13.5% in the overall population) and African-Americans were not represented (0% vs. 12% in the overall population). Finally, as some have pointed out (Berger, 1994), recent immigrant status is common among Westinghouse finalists. In the current sample, the trend is quite evident: 20 out of 55 (36%) had a father and 22 out of 55 (40%) had a mother either born elsewhere or first generation. Additionally, the cohorts are becoming more ethnically diverse over time, with percentages of non-European-Americans going from 2.6%, to 13.5%, to 17.9%, and finally to 34.1% from the 1965, 1975, 1985, and 1995 cohorts, respectively (χ^2 (3) = 14.43, p = .002).

Career Outcome Data

Each participant was asked for her or his resumé or curriculum vitae. If he or she did not respond, refused or could not be located directly, we attempted to gather career information from public sources such as CVs or resumés posted on personal, university or company web-pages.

The first outcome distinction was simply the highest level of education attained, namely the bachelor's, master's, or doctorate degrees and what they majored in or received their degree. Secondly, what percentage of the young and scientifically talented end up in scientific careers? If they stayed in science, did they enter academic or commercial professions and did they pursue physical science, biomedical science, or social science careers? If they did not stay in science, what kind of career (if any) did they pursue? Moreover, we developed a survey inquiring into possible reasons for why they did or did not pursue a scientific career path. With the lead question of "What led to your decision to pursue science?" some example answers rated on a 5-point Likert scale included "High degree of motivation in the topic," "encouraged by family, friends, or mentors," and "lack of motivation & interest in the topic." In order to index the kind and quality of career finalists had, we coded their CVs and resumes for positions held, and the number and timing of fellowships, honors and awards. Resumes were also coded for ultimate educational levels obtained, universities attended, first career positions and current career positions, and whether someone entered a science career and if so for how long. Career paths informed us, therefore, of who left science and when.

Procedure

Full names and addresses of the finalists from 1995, 1985, 1975, and 1965 were gathered initially from Science Service's database on the Science Talent Search (otherwise known as Westinghouse). As a supplemental source of address and biographical information we used Internet search engines (e.g., Google). Only names that could be positively identified were contacted or biographical information was gathered. The survey, a self-addressed stamped envelop, and two cover letters (one from the President of Science Service and one from the current author) describing the study's importance and asking for a current CV were sent to each address. Moreover, a website was developed that posted the survey for those who preferred electronic submission of their responses and CV's. We received some response (either survey or CV) from 69 of the 161 (43%) and survey responses from 55 (34%). In addition, we were able to obtain web-based career outcomes or CVs on 32 additional finalists, bringing the career-outcome sample size to 101 (63%). Analyses showed no differences on gender or ethnicity between those who responded to the survey and those who did not. There was a cohort (age) effect, however, with 43% (1965), 25% (1975), 20% (1985), and 51% (1995) of the cohorts responding ($\chi^2(3) = 11.47$, $p = .01$), that is, 1965 and 1995 cohorts were most likely to respond.

RESULTS

From analyses of degrees, careers, and honors we found that finalists were much more likely than normative samples to complete undergraduate and graduate degrees. Out of the 89 finalists we had definitive degree information on, 8 of them had the bachelor's as their final degree, 7 the master's degree, and 74 (83%) the doctoral degree (either the PhD or MD). For the entire population of finalists since 1942, 70% go on to earn the doctoral degree (Kaye, 2001), which is unusual even for a talented sample. For comparison, only 25% of Stanley's Study of Mathematically Precocious Youth (SMPY) participants earned doctorates, and only about 1% of the general U.S. population earns doctorate degrees (Benbow et al., 2000).

The majority (60.2%) of the bachelor's degrees were earned in the physical sciences (natural science, engineering, math, or computer science), 20.5% were earned in the biological-pre-med sciences, 3.8% were earned in the social sciences, 11.5% in the humanities, and 3.8% were unknown or unclassified. The breakdown of the doctoral degrees by general field of study was 27 of 78 (34.6%) were earned in the physical sciences, 45 (56.4%) in the biological–medical sciences, 3 (3.8%) in the social sciences, and 2 each (2.6%) were in the humanities and unknown. Between undergraduate and graduate degrees, in other words, there is a general migration from the physical sciences to the biological–medical sciences.

Moreover, the finalists earned their degrees at some of the most selective and elite universities in the country: Harvard (23), Princeton (10), MIT (7), Stanford (5), and Yale, Duke, Cornell, Columbia, and Northwestern each with two. It is worth noting, however, a cohort effect: 17 of the 23 Harvard undergraduate degrees were from the 1995 cohort; 5 of the 7 MIT degrees were from the 1965 cohort; and all 5 of the Stanford undergraduate degrees were from either the 1985 or 1995 cohorts. Graduate institutions were more evenly distributed, but Harvard still was the most frequently attended (11), followed by MIT (9), Berkeley (6), Stanford (6), Yale (4), and Caltech (3).

Career outcomes of the overall sample were as follows: 79 of the 100 finalists on whom we had career outcome data went on to pursue their education and/or a career in a scientific discipline, which broadly defined includes engineering, computer science, math, social science, and medicine. If someone went into a purely clinical form of medicine or psychology they were classified as having left science. Since the 1995 cohort was still either in training or just beginning their careers, we could not classify many of them on career outcome. Of the 83 careers we could confidently classify, 43% had left science broadly defined, 51% pursued careers in academic science, 23% in commercial-industrial science, and 4% in government science.

Westinghouse finalists as a group do garner awards and recognition for their continued excellence for scholastic and career achievements. For instance, in the entire population of finalists up through 1994 five have gone on to earn Nobel prizes, 28 have become members of the National Academy of Sciences, and at least eight MacArthur Fellows have been awarded (Berger, 1994). The current sample ($N = 50$) of 4 cohorts averaged 6.14 honors, awards, fellowships (SD = 6.32), with a median of 5.50, a mode of 6, and a range from 0 to 37. In addition to the various undergraduate and graduate awards and fellowships earned, among the career awards and honors were a MacArthur Fellow, a Sloan Fellow, an AAAS Fellow, a winner of the US Presidents Award, and even a Pulitzer Prize finalist. None of the 161 finalists in the 4 cohorts had earned membership in the National Academy (although the 1985 and 1995 cohorts are really not yet of age to be realistically eligible for NAS membership).

Interestingly and unexpectedly, finalists who earned bachelor and PhD degrees in science as well as those who pursued careers in science tended to have children at a younger age than those who left science. With degree and career in science coded dichotomously (0 = non-science; 1 = science), the point biserial correlations with age of first child were −.43 ($N = 21$, $p < .05$) for the undergraduate degree in science −.55 ($N = 21$, $p < .01$) for the PhD degree in science, and −.41 ($N = 21$, $p < .05$) for the career in science.

Questions from the survey revealed the mean age for first knowing when one wanted to be a scientist was 11.48 ($N = 48$), with a range from age 4 to 22. The items that were most endorsed concerned intrinsic forms of motivation (e.g., "satisfies my curiosity"), and those least endorsed concerned extrinsic forms of motivation (e.g., "financial security").

Gender and Westinghouse Outcomes

Ways in which male and female finalists are the same

Male and female finalists were equally likely to obtain bachelor and doctoral degrees, with 100% of the sampled men ($N = 55$) and women ($N = 23$) earning a bachelor's degree. Although there was a trend towards men (69%) pursuing more physical science (defined as physical science, computer science, math, or engineering) degrees at the undergraduate level more than women (46%), the effect was not significant (χ^2 (1) 4.47, $p = .11$). The discipline effect was even smaller at the PhD level, although again the tendency was for more men to pursue more physical science degree than women (39% vs. 25%; χ^2 (1) = 1.31, $p = .25$).

The number of honors (which includes fellowships, scholarships, and scholastic awards) did not differ for men and women either at the undergraduate or graduate levels. Nor were genders different on self-attributed reasons for why they pursued science, such as "It matches my talents and skills" and "I like the rigor and logical nature of the material." Men and women finalists did not differ on the age they first realized they wanted to be a scientist (males: $N = 33$, $M = 11.12$, $SD = 4.08$; females: $N = 15$, $M = 12.20$, $SD = 4.46$; t (46) < 1, ns, $d = .26$). Finally, men and women did not differ on the age at which they had their first child (males: $N = 17$, $M = 32.91$, $SD = 3.68$; females: $N = 7$, $M = 34.71$, $SD = 4.99$; t (22) < 1, ns, $d = -.41$).

Ways in which male and female finalists are different

An unusually high but marginally unequal portion of men (57/63 = 90.5%) and women (20/27 = 74.1%) for whom we have advanced degree information earned the doctoral (MD or PhD) degree (χ^2 (1) < 4.11, $p = .04$). Male and female finalists were not equally likely to stay in science after high school and pursue degrees and careers in science, medicine or technology. Around 78% of the women earned a bachelor's degree in a science, technology, or mathematics discipline, whereas 94% of the men did (χ^2 (1) = 4.40, p = .04). There was an even larger difference in attrition at the career level: 11% of men changed to non-science career paths, whereas 43% of women did so (χ^2 (1) = 12.88, $p < .001$). Looking more specifically at the different categories of science career, men were somewhat more likely to pursue non-academic science careers in industry and government (32% of males and 12% of females; χ^2 (2) = 10.79, p = .005), but men and women were equally likely to pursue academic science careers (42% of females and 54% of males). Only two of 12 motivation items differentiated the male and female finalists: males were more likely to say they do science because it "Satisfies my curiosity," whereas women were more likely to say they do science because "Science helps humanity."

As informative as the results are from a group that is selected for its potential, the question still remains: what kind of early careers and talent did those scientists have who in fact have gone on to have the greatest impact on their fields, namely members of the National Academy of Sciences? The second study addressed this question.

STUDY 2

The primary goal of the NAS study was to examine early life predictors of lifetime achievement and eminence in science. Specifically, when did the elite scientists first know they had talent for science and wanted to do science for a living, what role did families, mentors, teachers, and school experience play in their development as a scientist? In addition, what kinds of causes (personal or situational) did the NAS members attribute to their own success. Another question addressed in Study 2 concerned how productivity (i.e., publication rates) changes with age. There is a relationship between age and productivity in science (and other professions) and it is an inverted-U (Bayer & Dutton, 1977; S. Cole, 1979; Dennis, 1956; Diamond, 1986; Horner et al., 1986; Lehman, 1953, 1960, 1966; Over, 1982, 1989; Simonton, 1988a, b, 1991; Zuckerman, 1996). Further, once controls are made for different ways of operationalizing output, the curve peaks around 20 years into one's career, usually in one's early 40 s. To graphically model this relationship, Simonton has developed one of his better-known differential equations, with the peak occurring roughly 20 years into one's career and thereafter slowly declining (Simonton, 1988b). However, it does peak somewhat differently for various disciplines (earlier in math and physics, later in biology and geology). NAS members provide an ideal sample of highly productive scientists in which this model can be further tested.

A related question concerns whether producing works early in life predicts later levels of productivity. The empirical consensus is that early levels of high productivity do regularly predict continued levels of high productivity across one's lifetime (S. Cole, 1979; Dennis, 1966; Helson & Crutchfield, 1970; Horner et al., 1986; Lehman, 1953; Over, 1982; Reskin, 1977; Roe, 1965; Simonton, 1988a, 1991). Those who are prolific early in their careers also tend to continue to be productive for the longest periods of time.

METHOD

Participants

We contacted 321 members of the National Academy of Sciences (NAS) in two fields of biological science (cellular & developmental biology, and genetics), three fields of physical science (physics, astronomy, and chemistry), and two fields of social science (anthropology and psychology). Our goal was to receive responses from approximately 100 NAS members and we expected about a 33% return rate. Since women are a distinct minority in the NAS (approximately 2–5%) we selected every women member in the seven disciplines and every third man until we had approximately 45–50 targeted members per group.

We received questionnaire responses back from 97 out of the 321 (30% response rate), and due to the public nature of some information (e.g., websites and articles), we have some career data on at least 112 of the 321 (35%). More specifically, we had gender data on all 112, with 92 (82%) being male; ethnicity data on 104, with 101 (97%) being European-American and the remaining 3 being Asian-American; age data on 110 of the 112 (M = 69.80, SD = 10.99, range = 50–95); and immigrant status on 85 of the 112, with 28 (33%) having fathers and 29 (34%) having mothers who were immigrants or first generation Americans. Analyses showed no differences on age, gender or ethnicity between those who responded to the survey and those who did not.

Survey

Similar to the survey administered to the Westinghouse finalists, we administered an educational history, career, and motivation survey to NAS members. They were asked about when they and others realized they had talent for science, how well they did in high school and college, when they first published, what their motives for pursuing science were, and to rank order eight reasons they feel they had been so successful in science.

From CVs we gathered the career and productivity data (such as job titles, positions, universities, publication totals, and honors and awards received). The same criteria were used for publication and citation data as was used for the Westinghouse sample. For instance, only articles, chapters and books were counted as publications. Also citation data were coded from four distinct time periods: 1–5, 10–12, 20–22, and 30–32 years post PhD using *(Social) Science Citation Index*. This four-wave assessment allowed for trends in impact to be examined.

Procedure

Similar to the Westinghouse study, we gathered names from NAS membership lists posted on the web. We mailed a cover letter to the work addresses of each member describing the study and requesting a resume or CV. In addition, the Development of Scientific Interest Questionnaire was included along with a self-addressed stamped envelope. As was true of the Westinghouse sample, the survey was also posted on a password-protected webpage that allowed for the alternative electronic response of survey and/or CV submission.

Results

Descriptive Statistics

The NAS sample ($N = 96$) developed an interest in science at a very early age, with 25% knowing that they wanted to be a scientist by age 14, 50% knowing by age 18, and 75% knowing by age 20. In terms of first realizing they had talent for science, 25% of the NAS members realized their talent by age 13, 50% by age 16, and 75% by age 21. The age range was 5–33. Finally, NAS members began doing science early, with 75% having participated in formal research by age 21 (mean age = 19.2; median age = 20.0), and no gender difference between men and women.

Age of first published paper ranged from 16 to 30 ($N = 106$; $M = 23.57$, $SD = 2.82$; median = 23), with 25% of the sample having published their first paper by age 22, 50% by age 23, and 75% by age 25.25.

As mentioned above, publication and citation data are inherently positively skewed, and were so for NAS members. Means and standard deviations were 220.54 and 202.23 for publication and 1241.44 and 1169.94 for citations, respectively, which confirms their extremely high levels of productivity and impact on the field. The skewness score for publications was 3.30 and for citations was 1.59, suggesting that each distribution was positively skewed, as all distributions of publications and citations are (J. Cole & S. Cole, 1973; Feist, 1993; Simonton, 1988b). Therefore all analyses with publication and citation data were conducted on their log base 10 transformations. Furthermore, the relationship between productivity and impact was significant ($r = .48$, $N = 60$, $p < .001$), but less than the often-reported range of .65 to .75 (see Feist, 1997; Simonton, 1988a).

Growth Curve Models

Three unconditional growth curve models were constructed to test Simonton's curvilinear model of age and productivity (Simonton, 1988b), namely a linear model, a quadratic model, and a cubic model. Centering time on each individual's mean time, each model's time component for productivity was significantly different from zero: for the linear model $\gamma_{10} = .094$ (t (70) = 16.12, $p < .000$); for the quadratic model $\gamma_{20} = -.021$ (t (70) = −7.50, $p < .000$); and for the cubic model $\gamma_{30} = .006$ (t (70) = 6.86, $p < .000$). Deviance statistics, however, suggest that the quadratic model provided a better fit than the linear model ($\chi^2(3)$ 94.09, $p < .000$), and the cubic model a better fit than the quadratic model (χ^2 (4) = 51.18, $p < .000$) (cf. Singer & Willett, 2003). Using restricted maximum likelihood procedures in Hierarchical Linear Modeling (HLM), the cubic model provides 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 (see Fig. 1). A conditional model was then tested, in which age of first publication was used to predict the intercepts and growth curve trajectories of each model. Age of first publication did negatively predict the midpoints (intercepts) in each model ($\gamma_{10} = -.027$; t(69) = −2.27, $p = .02$), but not the trajectories (linear, $\gamma_{11} = -.003$, t (69) < 1, ns; quadratic, $\gamma_{21} = -.001$ t(69) = −1.29, p = 20; cubic $\gamma_{31} = .0004$, t (69) = 1.45, $p = .15$). These results suggest that those who start publishing earlier

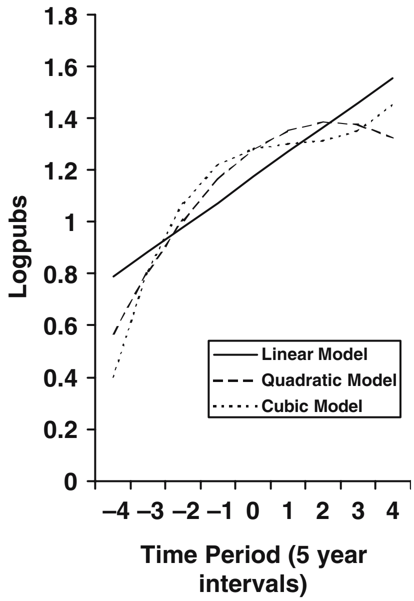

Fig. 1. Models of productivity over time for members of the National Academy of Sciences.

compared with later do have higher publication means at the midpoints in their career (time = 0), but do not have different, linear, quadratic, or cubic trajectories.

Motivation for Science

Similar to the Westinghouse sample, NAS members are driven by intrinsic enjoyment found in the scientific process rather than by external reward, especially money. In terms of their own self-assessed rankings of the reasons for their success, the top three reasons were "scientific intuition" (M = "intelligence," and "drive/persistence," whereas the bottom three reasons were "mathematical ability," "support from others," and "luck."

Scientific Precocity

Recall the prediction that age of talent should predict age of publishing and obtaining the PhD, which in turn should predict productivity and impact. Results showed that the four precocity variables were modestly positively correlated with age of first publication, which is an intermediate variable between precocity and achievement. In other words, the younger NAS members were when they and others recognized their scientific talent, when they wanted to be a scientist and when they first conducted scientific research, the younger they were when they published their first paper (see Table I). Age of first publication in turn was correlated with total publication rate over the lifetime, meaning the earlier one publishes the more productive one will be. This pattern of relationships from precocity to age of first publication to lifetime productivity implies an indirect connection between precocity and publication rate. The only precocity variable that reached the .05 level of significance with lifetime productivity was age that one first conducted formal research ($r = -.27$). In a more integrated multiple regression analysis, when four predictors were entered (age they recognized own talent, age they first conducted research, age of first publication, and age of PhD) in a model predicting publication total, 22% of the variance could be explained ($R^2 = .22$, F (4,62) = 4.39, $p = .003$). Holding the other predictor variables constant, the amount of unique variance explained (sr^2) by each predictor was .6%, .04%, 3.6%, and 5.30% respectively, with the last one (age of PhD) the only variable that by itself explained a significant amount of variance in publication total. Interestingly, none of the precocity variables were correlated with overall impact (citation rates) (see Table I). Finally, the older NAS members were when they recognized their

Table I. Correlations: Precocity Variables Correlated with Achievement Outcomes For Nas Members

	Achievement outcome			
Precocity variable	Age of first paper[a]	Age of PhD[b]	Publications[c]	Citations[d]
Age member recognized own talent	.25**	.27**	−.21a	−.03
Age others recognized their talent	.23*	.29**	−.14	.17
Age wanted to be a scientist	.24**	.22*	−.21a	−.12
Age first did formal science	.39***	.34***	−.27*	−.12
Age of first paper		.43***	−.38***	−.10
Age of PhD			−.34**	−.17

[a]*N*s range from 85 to 96; [b]*N*s range from 81 to 101; [c]*N*s range from 61 to 80; [d]*N*s range from 60 to 76.

scientific talent, the more children they tended to have (r (92) = .30, p = .003).

Gender Similarities and Differences

There were no gender differences in age of first published paper, age others recognized their scientific talent, age they first conducted research, or age of PhD (see Table II). Men and women were equally likely to be interested in science because it matched their talent, were good at it, found it esthetically appealing, and liked its logical and rigorous nature. Men were likely to be equally distributed across the physical, biological, or social sciences (33%, 34%, 33%, respectively; χ^2 (2) < 1, ns), and there was a non-significant tendency for women to be less in a physical science and more in a social science (20%, 35%, 45%, respectively; χ^2 (2) = 1.90, ns).

There was a modest but significant gender effect for the age that NAS members knew they wanted to be a scientist as well as when they realized their talent (see Table II). In both cases, men were younger than women. Men were likely to have their works cited by peers than women. There was a trend (p = .10) for men to publish more than women (see Table II). Women were more likely than men to be interested in science because they believed it solved important problems, it could help humanity, and because it satisfied their curiosity about the world.

GENERAL DISCUSSION

The current research has presented developmental findings from two different samples of elite scientists—one that showed tremendous talent while still in high school and the other that was deemed by peers to be doing the best science in the country. A largely implicit theme behind this research is that psychology as a field has much light to shed on scientific behavior, especially on the development of scientific interest and scientific achievement. If we want to understand who become the scientists of tomorrow and more particularly who becomes our best scientists, we need to supplement the methods and theories of philosophy, history, and sociology with those of psychology (Feist, in press; Feist & Barron, 2003; Feist & Gorman, 1998). In these two studies, my focus has been on developmental patterns of when different forms of scientific interest and behavior become manifest as well as the nature and extent of gender effects.

Table II. Gender Effects on Age, Productivity, and Motivation for NAS Members

Variable	Gender	*N*	*M*	*SD*	*T*	*p*	*d*
Age first conducted science	Males	77	19.28	3.28	< 1.00	ns	.03
	Females	18	19.18	4.11			
Age decided to be a scientist	Male	79	16.63	5.10	−2.24	.03	−.61
	Females	17	19.65	4.73			
Age realized you had scientific talent	Males	78	16.41	4.87	−1.92	.06	−.45
	Females	17	19.18	7.32			
Age others realized you had scientific talent	Males	70	16.70	6.00	−1.57	.12	−.37
	Females	15	19.93	11.55			
Age of PhD	Males	86	26.12	2.06	−1.39	.17	−.31
	Females	19	26.89	2. 81			
Age of first publication	Males	86	23.60	2.88	< 1.00	ns	.03
	Females	19	23.53	2. 61			
Total publications	Males	65	235.82	219.22	1.67[a]	.10	.42
	Females	17	166.00	113.85			
Total citations	Males	65	1367.94	1229.44	2.15[a,b]	.04	.90
	Females	13	608.92	448.70			
Helps humanity	Males	77	3.35	1.14	−2.52[b]	.02	−.62
	Females	16	3.94	0.77			
Solves important problems	Males	77	3.73	1.12	−2.03[b]	.05	−.49
	Females	16	4.19	0.75			
Satisfies curiosity	Males	78	4.53	0.78	−2.13[b]	.04	−.47
	Females	16	4.81	0.40			

[a]Due to skewed distributions of raw scores, *t*-test calculated on natural log transformed scores.
[b]Levene's test for homogeneity of variance revealed significant differences in variances and therefore *t*-test results for unequal variances are reported.

For the NAS members, age that scientific talent was recognized (both by self and others) has an important influence on early publication, which in turn is an important influence on lifetime publication rate. Precocity and its recognition are therefore crucial in getting the scientifically gifted on the path of a productive career in science. Early recognition of talent appears to be less critical for how influential one's career will be, at least in a sample that is already and by definition very influential.

On the question of developmental changes in scientific productivity, the current findings of NAS members are quite consistent with Simonton's curvilinear model where the peak tends to occur approximately 20 years into one's career, with a gradual decline thereafter (Simonton, 1988a, b, 1991). The current results, however, add a twist to Simonton's model: a cubic model with a second peak toward the end of one's career did a better job of explaining the data than did the single peak (curvilinear) model. Simonton has developed a complex theoretical model that attempts to predict and explain this age-productivity relationship by focusing on intrinsic factors, namely cognitive components (Simonton, 1988a, b, 1991). His theory is based on his notion of "chance-configuration" and consists of a few key assumptions: first, each creator starts off with a set amount of creative potential (number of contributions made over a normal, unrestricted life span). Second, the actualization of creative potential can be broken down into two components: ideation and elaboration. Ideation is the rate at which potential ideas are expressed, whereas elaboration is the rate at which ideas are put into concrete, public form. So, as each creator produces a new work she or he "uses up" some creative potential. The rate at which a creator actualizes potential and produces works is a direct function of the two cognitive transformations, ideation and elaboration.

One interesting commonality across both samples (Westinghouse and NAS members) is the realization at a young age that one wants to become a scientist (on average by age 12 for Westinghouse finalists and by age 18 for NAS members). Given that most college students change their major many times during their 4 years as an undergraduate, to have a group know by the end of high school or before that a particular career is right for them is quite remarkable. Early and clear insight into one's career calling is often an indicator that one knows where one's talents lies, and indeed such "crystallizing experiences" are frequently seen in adolescents who go on to be our most creative adults (Cameron, Mills, & Heinzen, 1995; Freeman, 1999; Gardner, 1993). The current investigations into the nature of elite science achievement only confirm the importance of early recognition of talent if creative potential is to become actual creative achievement in adulthood.

Another commonality between the Westinghouse finalists and NAS members is that they tend to be first or second generation American (cf. Berger, 1994; Helson & Crutchfield, 1970; Simonton, 1988a). Families who recently come to the shores of the U.S. may well foster a particular set of values that encourages and maybe even demands high level achievement, whether it be in science, medicine, or business. As suggested by classic work in the sociology of science, an interesting speculation on this phenomenon is that science may be more meritocratic than most other career paths and therefore talent and achievement in and of itself is more likely to be recognized and rewarded (see J. Cole & S. Cole, 1973; Merton, 1973). A significant scientific finding is perhaps more likely to be evaluated on its own merits than novel business or political ideas. Simonton (1988b) offers another possible explanation: "Individuals raised in one culture, but living in another are blessed with a heterogeneous array of mental elements, permitting combinatory variations unavailable to those who reside solely in on cultural world" (p. 126). Further research on the mechanisms that link immigrant status to scientific achievement is needed if we are to tease apart these alternative explanations.

Finally, analyses of attrition were only relevant to the Westinghouse sample and they showed that most finalists do tend to stay in science, math, or technology careers. And although female finalists were also very likely to earn a PhD in general, they are more likely than the male finalists to move away from science in terms of training and career, a finding that is consistent with Subotnik's work with the 1983 Westinghouse semi-finalists (Subotnik & Steiner, 1994), as well as with the study of mathematically precocious youth (Webb et al., 2002). It is important to note, as Webb and colleagues (2002) have recently, that just because women may opt out of science-oriented careers, does not mean they opt out of productive and achieving careers.

One goal of the psychology of science is to unpack some of the factors behind why women decide disproportionately to leave science, even those who are demonstrably among the most promising young scientists and mathematicians in the nation.

Some previous work suggests a few possible explanations: opting for and having greater talent for "people-oriented" rather than "thing-oriented" professions, differential effect of marriage and children, and differential response to highly competitive (cut-throat) work environments.

Vocational interest research suggests that there is a general gender effect along the "people-thing" continuum (Lippa, 1998; Prediger, 1982; Webb et al., 2002). The "People" end of the vocational dimension is mapped onto Holland's "Social" career types, whereas the "Thing" end of the dimension is mapped onto "Realistic" career types. According to Holland (1992) the social career type prefers occupations that involve informing, training, and enlightening other people. The realistic career type, on the other hand, prefers careers that involve manipulating things, machines, objects, tools, and animals. Building on Prediger's work, Lippa (1998) reported gender ratios of roughly 4 or 5 to 1 of males in Thing rather than People careers, and ratios of 2 or 3 to 1 of females in People rather than Thing careers. Interestingly, there were no gender effects on the Ideas-Data dimension. Similarly, Baron-Cohen and colleagues have published numerous studies on autism, Asperger's and theory of mind, and they consistently have found less people-orientation in boys compared to girls. Most intriguing and potentially relevant for the gender and physical science connection, they have found that engineers, mathematicians, and physical scientists score much higher on measures of high functioning autism and Asperger's syndrome than non-scientists (Baron-Cohen, Wheelwright, Stone, & Rutherford, 1999; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001; Baron-Cohen et al., 1998).

Such findings might explain the gender differences in physical versus social science, but they do not explain the relative gender equality in pursuing science while in school and the increasing gender disparity as one moves up the career ladder. One possible clue comes from the major life-events of getting married and having children. These developmental milestones seem to affect men's and women's career status and productivity differently, but not necessarily in the manner one might expect. A study by the National Research Council (NRC) for instance, reported that women who interrupted their careers for marriage and family in 1979 were less likely to obtain a tenure-track position, but there was no effect in 1995 (Long, 2001). For men, on the other hand, the effect of getting married and having children had a positive effect on productivity and this effect increased between 1979 and 1995. Marriage and children clearly add extra demands to the working life of women in science, whereas they appear to free up productive time for men. Such a conclusion is also consistent with the finding from the same NRC study that women in science historically were much less likely to get married and have children than men; that is, they seemed to have to make a choice that men did not, between having family or being a scientist (Long, 2001).

Surveys about reasons for initially being interested in science offer other possible clues for the "inverted-funnel" effect for gender-ratios over time. Seymour and Hewitt (1997), for instance, found that men seem to have more intrinsic reasons (e.g., good at it; enjoy it) for pursuing education in science, whereas women offer more extrinsic reasons (e.g., encouraged by family or teachers). When the social support and encouragement decline as one moves up the career ladder, motivational levels of women in science may also decline. More importantly, Seymour and Hewitt (1997) argue that the "cut-throat" and highly competitive nature of science education and career paths seem to affect men and women differently. Compared to men, equally capable women are more turned off by the highly competitive weeding-out environment of science and hence are more likely to turn their attention to less cut-throat environments for career opportunities.

The obvious next step in the research on the development of scientific talent, achievement, age, and gender would be to conduct similar psychological investigations into these samples but to use longitudinal methods. Rather than relying on self-reports, one could measure the change and growth in scientific interest, motivation, and ability from childhood through adulthood. Such an approach has been done with the mathematically gifted and with large gifted samples that ended up including some scientists, but not yet with the scientifically gifted per se (Benbow et al., 2000; Terman, 1955). By assessing these processes directly over time, one could start to get a handle on not only when scientific interest and talent develop, but one could also start to tease apart cause from effect.

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