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National-level Indicators of Androgens are Related to the Global Distribution of Scientific Productivity and Science Nobel Prizes

ABSTRACT

There are national differences in scientific activity that are not well accounted for by economic and intellectual factors alone. We examine the novel hypothesis that androgen levels may also play a role. Androgens are often referred to as male hormones, but are present in both men and women, and have been linked to performance in other domains, such as sports and entrepreneurship. National-level empirical data on scientific productivity, in terms of numbers of publications, and science Nobel laureates were compared to seven national-level androgen indicators; namely androgenic body hair, the length of the CAG repeat on the androgen receptor gene, prostate cancer incidence, male and female 2D:4D finger ratio, and sex frequency and number of partners. The majority of these indicators were associated in the expected direction with per capita number of scientific publications and Nobel prizes. Moreover, several indicators significantly interacted with national-level estimates of intelligence, such that androgen levels are related to measures of the scientific achievement only when the level of intelligence is relatively high. These findings may partly explain the global distribution of scientific productivity, achievements, and Nobel prizes.

Keywords: androgens, scientific activity, scientific productivity, Nobel prize, creativity, intelligence, intelligence quotient.

The Nobel Prize for science was founded in 1901 (and for economics in 1968) and is awarded annually to individuals who have made a major contribution to science (physics, chemistry, and physiology or medicine). Scientists who receive the Nobel Prize belong to the elite among their peers and have initiated a major shift in their scientific field.

Although the Nobel Prize is awarded to individuals, it also reflects information about the general scientific infrastructure in which the laureate operated. Specifically, science Nobel laureates often come from countries that show a high level of scientific productivity and activity in general (Nobelprize.org). Thus, Nobel prizes for the sciences as well as scientific productivity are not randomly distributed across the globe, but seem to cluster in certain regions or populations (see Murray, 2003 for a thorough analysis). Table 1 lists the 15 countries that have received the most Nobel prizes for science and economics per capita and the per capita number of citable scientific publications extracted from one of the largest publication databases in the world; Scopus (see Methods section).

Given this uneven distribution of scientific productivity and Nobel prizes across the world, a relevant question is what factors may influence this variation. Previous studies have suggested that environmental factors such as climate temperature or the levels of pathogens play a role (Murray & Schaller, 2017; Van de Vliert, 2017). Save for direct and trivial effects, such that it may be more difficult to work if it is very hot, these factors are believed to exert their influence through the individual. Achievement and creativity are commonly seen as the products of ability, effort, and opportunity, which obviously include both individual, cultural and economic influences (Hart, 2007; Kura, Te Nijenhuis & Dutton, 2015; Simonton, 1999a).

Opportunity relates mainly to infrastructure and economic factors, whereas ability and effort stem from numerous intertwined factors at the individual (e.g., personality, ability) and social (culture, bias) levels. Intelligence is a firmly established predictor of achievement in general, and for cognitively demanding tasks in particular (Rindermann & Thompson, 2011). The average intelligence quotient (IQ) of individuals

TABLE 1. List of Top 15 Countries in per Capita Citable Scientific Publications and Number of Nobel Prizes in Science (Excluding Literature and Peace Nobel Prizes)

Number of citable scientific publications per capita	Country	Number of Nobel prizes per million inhabitants	Country
0.052	Switzerland	3.84	Luxembourg
0.041	Sweden	2.48	Switzerland
0.040	Denmark	2.19	Austria
0.039	Finland	1.98	Denmark
0.037	Iceland	1.75	Sweden
0.034	Netherlands	1.46	UK
0.033	Norway	1.16	Norway
0.032	Australia	1.06	Netherlands
0.031	New Zealand	1.05	Germany
0.030	UK	1.01	Hungary
0.030	Belgium	1.00	USA
0.030	Israel	0.85	Cyprus
0.029	Canada	0.68	New Zealand
0.029	Singapore	0.62	France
0.028	Slovenia	0.57	Belgium

attending universities is one standard deviation above the national mean IQ (e.g., Dutton & Lynn, 2014; Murray, 2003; Simonton, 1999a,b). The level of intelligence required for achieving the original and substantial contributions that are typically rewarded with a Nobel Prize in science is conceivably even higher. The average IQ of PhDs in the hard sciences is somewhere around two standard deviations above the population mean (Dutton & Lynn, 2014), and Nobel laureates are furthermore the most intelligent scientists among their peers (Simonton, 1999a,b).

The association between intelligence and science may also be relevant to the observation that some countries display more scientific productivity and also, on average, win more science Nobel prizes than others. For example, several scholars have posited that countries differ in national mean IQ scores (see, Lynn & Vanhanen, 2006, 2012). A higher mean national IQ implies that the proportion of individuals having IQ scores above a certain high level (e.g., 130 or above) is also larger. Rindermann and Thompson (2011) referred to such highly intelligent individuals as the 'smart fraction', and argued that this smart fraction has a large impact on national economic and scientific success.

Thus, insofar as the estimates of national mean IQ have any merit, they can be expected to explain a relevant proportion of the distribution in Nobel laureates. Yet, intelligence alone may not be enough. For example, some countries have relatively few science Nobel laureates despite their having a good educational system and a relatively high national mean IQ, whereas other countries have a lower mean IQ but have produced a relatively large number of Nobel Laureates. Some Northeast-Asian countries have national mean IQ estimates that are higher than many Western countries, but have obtained fewer Nobel prizes per capita than would be expected based on their national IQ and educational system. Dutton, Te Nijenhuis and Roivainen (2014) noted that Finland has produced only two science Nobel laureates (and now one Economics laureate) despite its mean IQ and educational achievement (PISA scores) being the highest in Europe.

These observations indicate influences of factors besides intelligence and the level of economic and educational development on the production of scientific publications and attainment of Nobel prizes. While intelligence is necessary for handling complex tasks such as scientific design and statistical analysis, personality factors play a more prominent role for scientific creativity above an IQ of about 120 (Eysenck, 1995). Nobel laureates and scholars of that caliber may be characterized as obsessively curious and driven, devoting extraordinary amounts of time to their pursuit, and making sacrifices of a magnitude often well beyond that of the top tier in science.

In terms of personality, novelty and creativity are associated with psychoticism and openness to experience (Grosul & Feist, 2014), single-minded devotion, and a lower proneness to social conformism and groupthink (Dutton & Van der Linden, 2015). There is some evidence that these factors are in turn associated with androgens (Herbert, 2015; Zuckerman, 2013). Here, we examine the novel hypothesis that higher levels of androgens are associated with greater scientific productivity (number of publications) and excellence (the probability of receiving a Nobel Prize) at the national level. Thus, it may contribute to explaining the present distribution of these measures across countries.

ANDROGENS AND BEHAVIOR

Androgens refer to hormones involved in the development and maintenance of male characteristics in vertebrates, but they are also present in females. Testosterone is the most well-known androgen, with strong effects on development and manifestations of male sexual characteristics, but other natural androgens are 5-alpha dihydrotestostereone (DHT), androstanediol, androstenedione, dehydroepiandrosterone, and androsterone (Chang, 2002).

Androgens can have both *organizing* and *activational* effects (Browne, 2006). Organizing effects mainly refer to the influence of androgens on the brain, and relate typically to the level of exposure to androgens in utero. One relevant effect in the context of scientific productivity may be an increased interest in systems and systematizing and a decreased interest in empathizing and interpersonal relations (Su & Rounds, 2015; see Baron-Cohen, 2010; and Lippa, 2010; for comprehensive reviews). Activational effects refer to the influence of circulating hormones in the body on behavior. For example, the level of circulating androgens has been associated with aggression and dominance (Eisenegger, Haushofer & Fehr, 2011; Mazur & Booth, 1998). Androgens play a role in libido in both males and females (Pfaff, 1997) and are associated with interest in, and the frequency of, sex in both males and females (Bancroft, 2005). Moreover, disorders that reduce the levels of androgens, or reduce sensitivity to, androgens are related to decline of sexual functioning. Men with Kallman syndrome lack an adequate signal from the brain to the testes to produce testosterone, causing a near complete lack of sexual interest (Bancroft, 2005; Pfaff, 1997).

Particularly relevant for the present study is that high levels of androgens are accompanied by higher levels of competitive drive, risk-taking, and aggression (Browne, 2006; Eisenegger et al., 2011). These traits are related to the motivation to achieve scientific excellence (Feist, 1998; Simonton, 1999a) and hence indirectly to the probability of becoming a science Nobel laureate, which is related to novelty and creativity on many levels. While the number of scientific papers is presumably related to their conformity, lack of controversy, and level of establishment of the field, novel ideas typically face considerable resistance. Both the ideas, theories, empirical data, publications, and the authors themselves are often met with severe criticism before they become accepted in the scientific community. Although generally awarded when the research has become established, many years after being published, a Nobel Prize is typically given to the forerunners, the scientific avant-garde. Engaging in scientific competition and controversy is therefore often a prerequisite for producing an idea of Nobel magnitude. For example, Watson, Crick, and Wilkins won the price because they were the first to publish their findings on the structure of DNA, although other people were on the same track and would have been soon to follow. A number of studies (e.g., Eysenck, 1995; Simonton, 1999b) concur that becoming a highly original scientist is predicted by extremely high intelligence combined with several personality characteristics that are known to be influenced by androgens, such as high competitiveness, high risk taking, low agreeableness and low conscientiousness (Zuckerman, 2013).

The research literature provides some empirical and theoretical support for this idea. Lebuda and Karwowski (2016) showed that facial width-to-height ratios, an indicator of testosterone exposure, moderated the association between the frequency of being nominated and obtaining a Nobel literature Prize in 44 laureates and 368 nominees. The same scholars (Karwowski & Lebuda, 2014) found that the second-to-fourth (2D:4D) digit ratio, another presumed androgen indicator, predicted eminence in Polish actors.

Insofar as the link between androgen levels and creativity/eminence has any merit, one would expect that country-level variation in average androgen levels or sensitivity, as some previous studies have suggested (Dutton, van der Linden & Lynn, 2016; Westlund, Oinonen, Mazmanian & Bird, 2015), may partially underlie overall scientific productivity and the likelihood of an individual winning a science Nobel prize. The most direct way to test this proposition is to compare the androgen levels of high-productive scholars and Nobel laureates with those of less productive and successful scientists. This is not feasible because androgen data for these individuals are not available, and it is highly unlikely that a substantial proportion of such eminent individuals would care to make them available at the individual level. Likewise is there, to the best of our knowledge, currently no study that examines the direct associations between androgen levels and scientific productivity in a wide range of countries. Regardless of the type of excellence considered, collecting such data would be a tremendous long-term project requiring large amounts of research resources. In lieu of such possibilities, we adopt a national-level differences approach as a first test of the androgens-scientific productivity

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hypothesis. The question is addressed as to whether the number of scientific publications and science Nobel prizes per capita are related to national-level indices of androgens and IQ. It is hypothesized that the number of publications as well as the probability of producing a science Nobel laureate are both related to national androgen levels, while mean national IQ explains an even larger part of the variance.

NATIONAL-LEVEL ANALYSES: CAUSAL AND CONFOUNDING EFFECTS?

When considering data at the national or population level, there is a range of potential confounding and complicating factors. One is that population properties often vary across cultural clusters and hence across regions that may not follow national borders (Ward & Gleditsch, 2008). More specifically, regions differ in characteristics such as economic prosperity, level of freedom/democracy, well-being, health, crime rates, and birth rates, and environmental factors such as climate (Karwowski & Lebuda, 2013; Van de Vliert, 2013) and level of pathogen stress (Murray, Trudeau & Schaller, 2011). In the real world, and without the possibility of conducting controlled experiments, it is therefore, impossible, for the most part, to distinguish between variables in terms of cause and effect. For instance, causality may empirically be inferred when change in one variable precedes a reliable change in another. A causal link may also be theoretically more or less likely: that weather conditions affect human thoughts and emotions rather than vice versa. However, the very complex nature of the human condition makes it inevitable that most variables will exert some influence on many other variables, at least some of the time and for some individuals. This is a notorious methodological problem, especially for multivariate predictive modeling. For the present study, a key question is therefore which variables should be considered independent (i.e., causal) and which should be considered as alternative explanations or control variables, also bearing in mind that there may be identified or non-identified confounding variables. Another problem is that statistically controlling for certain variables reduces or even obliterates the effects of the predictors if they are correlated with the control variables (Angrist & Pischke, 2008). Indeed, the kind of variables we consider here are likely to be correlated on the national level, because they are ultimately related across explanatory levels. For example, conditions that exert a certain genetic selection pressure will eventually alter traits and hence behaviors in the population. Certain genotypic properties will likewise eventually affect the social and even the physical environment. Our approach to these problems is simple and straightforward. While acknowledging an unlimited chain of causal relations across multiple levels of explanation (e.g., genetic, trait psychological, social, and environmental), we argue that proximal explanations at the phenotypic level are the most direct cause and hence always relevant and useful for understanding behavioral phenomena. To examine their potential explanatory value, we should control for variables on the same but not on other levels of explanation. Climato-economic factors that may influence national-level differences in cultural factors such as science, democracy, crime, and prosperity (Van de Vliert, 2013, 2017; Murray et al., 2011; Murray & Schaller 2017) may be ultimate rather than proximate in nature, with the exception of direct and trivial effects, as mentioned before. Although we acknowledge that temperature and other environmental factors can influence behavior and its outcomes, the psychologically significant effects are conceivably rather conveyed through stable trait state characteristics of individuals, which will in turn manifest themselves in cultural, political, and economic outcomes. As a point in case, Lynn and Vanhanen (2012) considered no less than 244 national-level variables that all correlated with national-level IQ estimates, which led them to propose a

> ...three stage causal model in which geographic and climate factors have been responsible for differences in national IQs, and differences in national IQs are responsible for significant proportions of the variance in national-level differences in educational, economic and a large number of other social phenomena (p. 233)

A similar possibility was recently mentioned by Van de Vliert and Murray (2018) who argued that the effects of climate may work through its influence on various population characteristics.

When following this line of reasoning for androgens it can be considered a viable option that, beyond intelligence, androgens may also exert causal effects upon national-level variables such as scientific productivity, and perhaps economic prosperity and the type of political system. Accordingly, climate and pathogen levels can indeed be expected to show strong correlations with cultural outcomes, but not because they are directly causal to the outcomes, but rather because the environmental factors have shaped the characteristics of the population.

The crux of this issue is that controlling for particular factors such as GDP, climate or pathogens, presupposes that they are exclusively causal, while many of these factors are in fact interdependent and would take away a relevant share of the true variance. Hence, decisions about which factors are more likely causal (e.g., climate, pathogens, and GDP versus IQ and androgens) and which are manifestations should be mainly guided by theoretical considerations.

This being said, we submit that it would nevertheless be useful to consider the present androgen hypothesis in relation to the influence of other 'usual suspects' such as the variables described above. As such, the present study also includes these alternative national-level variables and tests how they relate to the androgens-science link.

Another potential issue mentioned in national-level studies is that spatial proximity may have a general influence on clusters of countries, thereby violating the assumption that countries are independent data points. Some scholars have suggested to control for the proximity in order to deal with this (e.g., Ward & Gleditsch, 2008). Others, however, have argued that such an approach would be misleading when the focus of analysis is on population characteristics instead of the nation itself (e.g., Minkov, 2012). For example, European countries are relatively distant from the US and Australia, yet have large economic and cultural overlap because they largely constitute populations with similar characteristics. Other countries are relatively close to each other yet differ vastly in economic and cultural factors, such as Indonesia and Australia. Another example would be Finland and Sweden who are actually neighboring countries, yet it has been proposed that Finns have a relatively high proportion of Asian genes, which allows a possibility that in terms of androgen indicators they may have more similarities to North-East Asians than other European populations (see, e.g., Dutton et al., 2016). Thus, the absolute geographical distance is probably not the crucial factor, but rather population characteristics.

In conclusion, we test the hypothesis outlined above by examining the relation between national-level empirical data on the numbers of scientific publications and science Nobel laureates and seven androgen indicators.

METHODS

GENERAL APPROACH AND PROCEDURES OF DATA COLLECTION

For as many countries as possible and based on scientific peer-reviewed literature, data were collected regarding national IQ estimates, the number of citable scientific publications, the number of Nobel prizes, and a range of national-level androgens indicators. In addition, national-level data were collected on a range of alternative variables that have been mentioned in the literature (see below).

Regarding androgen levels, obtaining direct estimates of androgen in various countries would have been preferable. Yet, although some smaller studies with specific samples compared various national groups (e.g., Chin et al., 2013; Santner et al., 1998), there seems to be remarkable lack of cross-cultural studies with national representative samples that have directly compared androgen levels. Similar to previous studies (e.g., Dutton et al., 2016; Westlund et al., 2015), we therefore used a set of indirect indicators of the level of, or sensitivity to, androgens. They were selected on the basis of two criteria. First, there had to be clear scientific evidence or some level of agreement among scholars that the indicator has a relationship with androgens. Second, data had to be available for a reasonable number of different countries, which turned out to be a bottleneck for the number of countries that could be included. Consequently, information was obtained about a relatively large number of countries on scientific publications, Nobel prizes, and IQ, but the androgens indicators were compiled from a smaller number of countries that did not always fully overlap. Because of this, the specific *N* of the analyses varies across the indicators. Table S1 in the supplementary material lists which indicators were available for which country (see also below).

NUMBERS OF PUBLICATIONS, SCIENCE NOBEL PRIZES, AND IQ ESTIMATES

Scientific publications

The number of scientific publications was obtained from the website SJIamgo Science and Country Ranking (www.SJImagojr.com), which provides the number of scientific publications in SCOPUS across all disciplines between 1996 and 2015. The number of citable publications per country was divided by the population to obtain an estimate of per capita productivity, henceforth called 'publications'.

Nobel prizes

The number of Nobel prizes per country was obtained from the official Nobel Prize website (Nobelprize.org), including Physics, Chemistry, Physiology or Medicine, and Economics. This number was also divided by the population, in millions, to obtain an estimate of per capita Nobel prizes, henceforth called 'Nobel prizes'.

Mean national-level intelligence estimates

The national IQ scores were acquired from the work of Lynn and Vanhanen (2002, 2006, 2012). The first estimates of national IQs were reported in 2002, and were updated in 2012. Here, the most recent national IQ estimates reported by Lynn and Vanhanen (2012) are used, comprising 168 countries.

NATIONAL-LEVEL ANDROGEN INDICATORS

Androgenic hair

Androgen levels are associated with hirsute, one established proxy for which is the number of hairs on the mid-phalangeal segment of the 4th digit (i.e., the middle segment of the ring finger). A number of reviews and meta-analyses have compiled data on the proportion of people having mid-phalangeal hair in various countries (Hindley & Damon, 1973; Westlund et al., 2015), based on which Dutton et al. (2016) reported estimates of the proportion of the population with mid-phalangeal hair (MPH) for 124 countries. No estimates were present for South-American, and Southern and central African countries.

CAG repeats in the AR gene

Minkov and Bond (2015) tested national differences in certain evolutionary reproduction strategies using genetic polymorphisms. As part of their study, they collected national-level data on the characteristic of the androgen receptor (AR) gene that holds the recipe for building a complex protein structure that is the main conveyor of testosterone effects. This AR gene displays polymorphisms at several locations, of which the repeat number variation of the CAG triplets is the one most widely investigated. Individual differences in the number of CAG triplets (shorter vs. longer) are correlated with the sensitivity of the androgen receptors. Here, we use the estimates of mean national levels of CAG repeat number compiled by Minkov and Bond (2015; see also Dutton et al., 2016). Shorter CAG repeat length is associated with a higher number of sexual partners and violent and impulsive behavior (see Manning, 2002, for a review). CAG length was obtained for 50 countries, which included several European, African, and Asian countries. No data were available for South-American countries.

Prostate cancer incidence

Prostate cancer risk is influenced by genetic and various environmental factors, such as diet. Yet, it is also widely acknowledged that androgens play a role in the risk of developing prostate cancer, including interactions between in utero exposure and circulating androgens during one's lifetime (Gann, Hennekens, Ma, Longcope & Stampfer, 1996). Here, we used the most detailed international prostate cancer incidence numbers available, reporting incidence rates per 10,000 for 32 countries, including the USA, Canada, and several European, African, and Asian countries, but no South-American country (Haas, Delongchamps, Brawley, Wang & De la Roza, 2008).

2D:4D digit ratio

The 2D:4D is the ratio between the lengths of the index finger by the ring finger, and has been used in several hundred studies as a putative indicator of prenatal androgen exposure (for a review see Manning, 2002). A lower ratio is assumed to indicate higher androgen exposure. Although there is some debate about the specific nature of the relation between the 2D:4D ratio and androgens, and the measure appears to be rather unreliable for small samples, the validity seems rather strong. Rahman et al. (2011) showed that a higher 2D:4D ratio is related to a lower likelihood of developing prostate cancer. Moreover, the 2D:4D ratio has been linked to a wide range of masculine traits such as dominance, competitiveness, and Asperger syndrome and other autism spectrum disorders. It is important to note that the 2D:4D ratio seems to predominantly reflect organizing effects of early androgen exposure, rather than actual circulating androgen levels.

We used the largest national-level compilation of 2D:4D ratio estimates so far (Manning, Fink, & Trivers, 2014; see also Manning & Fink, 2011), which covers 29 countries, 23 of which overlapped with those included in the present study.

Sociosexual behavior

Libido is influenced by androgens (Bancroft, 2005; Eisenegger et al., 2011). Also, it is well established that overt sexual behavior partly reflects libido. There is a large study on this topic conducted by a company that produces condoms worldwide (Durex, 2005). This study included measures of the self-reported annual sex frequency and the number of sex partners, which have been used as indicators of sexual behavior in previous studies (e.g., Dutton et al., 2016). The study contains data on 41 countries from different continents, but does not include African countries. The mean annual sex frequency (averaged over men and women) was 103.15, but large variation exists between countries ($SD = 17.72$).

CONTROL VARIABLES

To address the alternative explanations described in the introduction, we collected GDP, level of democracy, average climate temperature, and level of pathogens in the environment.

Gross domestic product (GDP) per capita

GDP was extracted from the website of the International Monetary Fund (IMF, 2015).

Democracy index

A country's democracy index was obtained from the Economics Intelligence Unit (2012) which is based on 60 indicators of the political system, such as the level of participation, functioning of the government, and civil liberties.

Average climate temperature

The average annual climate temperature per country was extracted from the list of average temperatures between 1961 and 1990 from the Lebanese Economy Forum (2015).

National pathogen level

Information about the prevalence of pathogens in the environment was obtained from the study of Murray and Schaller (2010), who provided the average levels of pathogens within 230 geopolitical regions worldwide. The estimates were based on seven and nine pathogens, and we used the seven pathogen estimate because it covered more countries. The two versions were strongly correlated anyhow ($r = 96$).

STATISTICAL ANALYSIS

The zero-order correlations between the androgen indicators and the science measures were first examined. Due to obvious skewness in the data (some countries produced relatively many laureates, many countries did not), non-parametric Spearman correlations were used. Pearson correlations were also calculated for validation. The relationship with IQ was assessed with three different complementary approaches for asserting the robustness of findings. First, the correlations were calculated only for countries with an average estimate of IQ greater than 90. Although such a criterion by definition has some level of arbitrariness, a breakpoint of 90 in IQ retained 98% of the winning countries, which in itself already supports the notion that average individual characteristics relate to national-level science outcomes. Second, the partial androgen-science correlations were calculated, controlling for IQ. Third, androgen-IQ interactions were tested by means of regression by adding standardized main effects in Step 1 and the interaction in Step 2.[1]

RESULTS

The zero-order correlation (Spearman's rho) between national number of per capita publications (*publications*) and Nobel prizes was $r(153) = .67$ ($p < .001$), indicating a strong relationship between overall national scientific productivity and the probability of obtaining a Nobel Prize. The intercorrelations between the androgen indicators are listed in Table 2. Although effect sizes were often substantial, only 25% of them reached significance at the $p < .05$ level due to the relatively low N in some cells. Nevertheless, 17 of the 21 correlations were in the expected direction, and 10 can be considered moderate effects, according to Cohen (1977). The pattern of intercorrelations between the indicators suggests the presence of a latent androgen factor. However, there were too few countries that had data for all of the seven indicators to obtain a reliable latent factor. Nevertheless, to get an indication of how such a factor would look like, we conducted factor analyses on various combinations of the indicators. The results of those analyses are reported in the supplementary material in Table S2. For each factor analyses, the N was obviously too small to draw strong

[1] Main and interaction effects were also tested for validation purposes, using ANOVAs. Androgen indicators split by median value was a factor and IQ higher versus lower than 90 was another factor. These analyses confirmed the results as reported in the manuscript, since none of the conclusions changed after using these parallel analyses. For space-saving reasons, the ANOVA results are not reported if they did not differ from the regression results. Full ANOVA results can be obtained upon request from the first author.

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TABLE 2. Spearman's Rho Correlations (and Ns) Between the Various Androgen Indicators

	1	2	3	4	5	6	7
1. Androgenic hair	—						
2. CAG repeat	−.18 (43)	—					
3. Prostate cancer	.67** (25)	−.42 (14)	—				
4. Male digit ratio	.26 (23)	−.08 (17)	−.77** (11)	—			
5. Female digit ratio	−.11 (23)	.06 (17)	−.23 (11)	.43* (23)	—		
6. Sex frequency	.49** (38)	−.55** (28)	.41† (18)	.33 (22)	.36† (22)	—	
7. # Sex partners	.22 (38)	−.31† (28)	.64** (18)	−.35 (22)	−.16 (22)	.29† (41)	—

Note. $^{**}p < .01$; $^{*}p < .05$; $^{\dagger}p < .01$.

conclusions ($N = 5$ to 22). Yet, the analyses consistently indicate that a general factor is present that explains, on average, 66.11% of the variance (range 44.78 to 79.16%). Countries with a higher incidence of prostate cancer had significantly higher estimates of androgenic hair, lower male digit ratios, and a higher average number of sexual partners, and a tendency for a higher sex frequency. In the supplementary material, we also show how those latent factors relate to the science outcomes. In general, the latent androgen factor is associated with the science outcomes in the expected direction. However, due to relatively low overlap on some indicators the results of those analyses should be interpreted with high caution. Each indicator will therefore next be analyzed separately with regard to their relation to the science and Nobel Prize measures.

Table 3 shows that IQ at the national level was strongly related to both *publications* and science Nobel prizes. More importantly, however, six out of the seven androgen indicators were significantly correlated with *publications*, and three out of seven were significantly correlated with Nobel prizes, all in the expected direction. Effect sizes were often quite substantial, even for the non-significant findings (.25–.41; Cohen, 1977). A notable exception was a positive correlation between CAG length and both *publications* and Nobel prizes, but this pattern was reversed when IQ was controlled for.

When only considering countries with a mean IQ estimate higher than 90, most of the previously significant correlations remained significant. The only exception was the female digit ratio × Nobel prizes correlation, which decreased from −.47 to −.41 (n.s.). The Nobel prizes with number of sexual partners correlations went from a non-significant .26 to a significant value of .33. Despite some small differences in reaching the somewhat arbitrary $p = .05$ significance level, it is clear that the effect sizes remained relatively stable. The correlations for CAG length reversed sign and became negative and significant for *publications* and Nobel prizes. This is consistent with the hypothesis that androgens become more important when IQ is sufficiently high. When controlling for IQ, five androgen indicators remained significant for *publications*, and two for Nobel prizes, as seen in the corresponding columns in Table 3.

The regression analyses revealed that androgenic hair estimates significantly interacted with IQ for *publications* and Nobel prizes (see Table 4A and B). Figure 1 illustrates the nature of these interactions as indicated by posthoc tests. Androgen levels do not significantly relate to *publications* and Nobel prizes when average IQs are low, in which case they even exhibit a slight negative trend. However, the level of androgenic hair was associated with more *publications* and more Nobel prizes when mean IQ is higher than 90. The interaction for prostate cancer incidence showed the same interaction pattern for *publications*, but not for Nobel prizes. None of the other interactions reached significance (all $p > .05$).

ALTERNATIVE EXPLANATIONS OR CONTROL VARIABLES

Various national-level variables were mentioned in the introduction, which in the literature have been suggested as causal factors for several economic and cultural outcomes. We argued that controlling for such variables and interpreting the results should be employed with caution and be based on theoretical grounds. Nevertheless, we conducted the standard multivariate control analyses to explore the role of several of those variables, as required by an anonymous reviewer. Table 5 shows zero-order Spearman correlations between the two science variables and four alternative national-level variables (including their intercorrelations), namely GDP, political freedom (democracy index), average climate temperature, and the prevalence of pathogens. As, in contrast to the androgens indicators, those indicators *were* available for almost every country, it was also possible to extract a single factor with an Eigenvalue of 2.57 that accounted for 54% of the variance among these variables. The loadings of this factor on the four variables were substantial, namely

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TABLE 3. Correlations Between Publications per Capita and Nobel Prizes per Capita with IQ and Androgen Indicators (*N* Within Brackets)

	Number of scientific publications				Nobel prizes			
	r (overall)	*r* (IQ >90)	Partial *r* (control for IQ)	Partial *r* (control for GDP)	*r* (overall)	*r* (IQ >90)	Partial *r* (control for IQ)	Partial *r* (control for GDP)
IQ	.62 (96)**	.35 (54)*	—	.41 (93)**	.39 (153)**	.16 (60)	—	.12 (149)
Androgenic hair	.59 (115)**	.53 (57)**	.26 (112)**	.38 (112)**	.41 (120)**	.40 (57)*	.21 (116)*	.21 (116)*
CAG-repeat	.32 (47)*	−.41 (31)**	−.32 (44)	−.05 (44)	.17 (51)	−.42 (31)**	−.21 (48)	−.07 (48)
Prostate cancer	.83 (24)**	.70 (18)**	.74 (21)**	.46 (21)*	.68 (32)**	.49 (18)*	.53 (29)**	.34 (29)
Male digit ratio	−.51 (23)**	−.55 (21)**	−.38 (20)**	−.34 (20)	−.25 (23)	−.25 (21)	−.30 (20)	−.01 (20)
Female digit ratio	−.75 (23)**	−.70 (21)**	−.57 (20)**	−.53 (20)*	−.47 (23)**	−.41 (21)	−.13 (20)	−.14 (20)
Sex frequency	.07 (41)	.01 (34)	.22 (38)	.29 (38)	.10 (41)	.07 (34)	.16 (38)	.18 (38)
# Sex partners	.42 (41)**	.59 (34)**	.59 (38)**	.33 (38)*	.26 (41)	.33 (34)*	.30 (38)	.14 (38)

*$p < .05$, **$p < .01$.

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TABLE 4. Interaction Tests. (A) Results of the Regression Analyses for Androgenic Hair and Prostate Cancer on Number of Publications. (B) Results of the Regression Analyses for Androgenic Hair on Nobel Prizes

		β	$R^2\Delta$		B	$R^2\Delta$
(A)						
Step 1			.41***			.83***
	IQ	.39***		IQ	.45***	
	Androgenic hair	.30**		Prostate cancer	.56**	
Step 2			.25***			.04*
	IQ	.79***		IQ	.80***	
	Androgenic hair	.18*		Prostate cancer	.15	
	Andr. hair by IQ	.59***		Prostate by IQ	.40*	

		β	$R^2\Delta$
(B)			
Step 1			.19***
	IQ	.19	
	Androgenic hair	.28*	
Step 2			.16***
	IQ	.52***	
	Androgenic hair	.19	
	Andr. hair by IQ	.50***	

***p < .001, **p < .01, *p < .05.

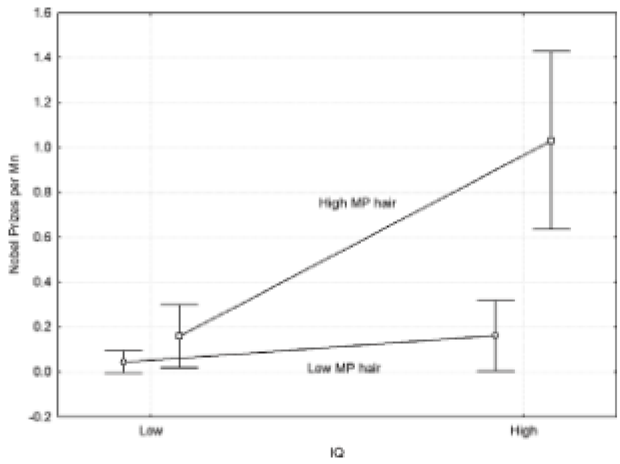

FIGURE 1. Interaction between androgenic (mid-phalangeal) hair and IQ on Nobel Prizes.

−.62, −.62, .70, and .96 for GDP, democracy, temperature, and pathogens, respectively. Thus, higher scores on the factor indicate a generally unfavorable economic, political, and environmental situation, which is somewhat similar to the climate-economic threat as referred to in previous studies (Murray & Schaller, 2017; Van de Vliert, 2017).

Table 6 shows the correlations between the androgen indicators and the science measures (*publications* and Nobel prizes), controlling for this general environmental factor. These analyses were conducted on the whole sample of countries, as well on those in which the estimated IQ is higher than 90. For the Nobel prizes, none of the correlations reached significance. For *publications*, however, several correlations remained

TABLE 5. Correlations of Alternative National-level Characteristics (*N* Varies From 146 to 165)

	1	2	3	4	5	6
1. Publications per capita	—					
2. Nobel prizes	.67	—				
3. GDP	**.91**	**.59**	—			
4. Democracy index	**.72**	**.62**	.63	—		
5. Average temp.	**−.51**	**−.53**	−.42	−.41	—	
6. Pathogens	**−.66**	**−.50**	−.65	−.50	.62	—

Note. All correlations were significant at $p < .001$. Correlations in bold emphasize the correlations between the environmental measures and the science measures.

TABLE 6. Androgen Indicators and Science Measures, Controlling for the General Environmental Factor (Consisting of GDP, Democracy, Temperature, Pathogens)

	Publications per capita		Nobel prizes	
	All countries	IQ >90	All countries	IQ >90
Androgenic hair	.20 (107)*	.39 (41)*	.04 (109)	.22 (41)
CAG length	.05 (46)	−.34 (24)†	−.16 (46)	−.23 (24)
Prostate cancer	.49 (29)**	.34 (14)	.29 (29)	.12 (14)
Male digit ratio	−.38 (20)†	−.42 (19)†	.02 (20)	.04 (19)
Female digit ratio	−.68 (20)**	−.69 (19)**	−.25 (20)	−.31 (19)
Sex frequency	−.28 (37)	−.23 (31)	−.18 (37)	−.15 (31)
# Sex partners	.23 (37)	.46 (31)*	−.02 (37)	.04 (31)

Note. *N* within parentheses. $^{**}p < .01$; $^{*}p < .05$; $^{\dagger}p < .01$.

significant or otherwise showed a clear trend ($p < .10$). For example, for the whole sample, three out of the seven correlations remained significant, and one exhibited a trend. For countries with estimated IQs above 90, three out of seven correlations remained significant and two exhibited a trend.

DO NOBEL LAUREATES REPRESENT THE POPULATION OF THEIR COUNTRY?

It might be argued that Nobel laureates are not always representative of the population or majority group in their country. However, a check revealed that the laureates are mostly members of the majority group in their country. The exceptions are Brazil (1 out of 1 to a Briton), Bulgaria (1/1 to a German), Finland (2/3 to the country's Swedish-speaking minority), Romania (1/2 to a Hungarian), and South Africa (4/4 to individuals of European/Dutch descent). Slovenia's only science laureate had a Slovenian parent and an Austrian parent and South Korea's science laureate has a Norwegian father and a Japanese mother.

Apart from these specific exceptions, it is clear that individuals with an Ashkenazi origin are strongly overrepresented among Nobel laureates, with 31% of the USA Science Nobel prizes, compared to around 1.7% of the USA population, and 21% of the total number of Science Nobel prizes across all countries, compared to approximately 0.2% of the total population in the world (for a review, see Lynn, 2011). In line with those numbers, it was considered relevant to examine the influence of this specific group on the findings reported above. The correlations between the androgen indicators and science measures were therefore recalculated using the number of Nobel laureates per country sans those of Ashkenazi origin. Table 7 shows that these correlations do not differ substantially from those in Table 3.

DISCUSSION

The present study provides, for the first time, indications that androgens play a role in scientific productivity. One of its strengths is that these results were not based on data from a single method or one specific research group, but rather included several types of indicators from widely diverse sources, namely from the genetic, physiological, anthropological, and psychological domains. Likewise, the dependent variables were based on large-scale bibliometric and concrete data across disciplines and institutions,

TABLE 7. Correlations Between Nobel Prizes per Capita and National-level Androgen Indicators (*N* Within Parentheses) Excluding Nobel Prizes Awarded to Scholars of Ashkenazi Descent

	r (overall)	*r* (IQ >90)	Partial *r* (controlled for IQ)
Androgenic hair	.56 (115)**	.33 (57)*	.23 (112)**
CAG-repeat	.17 (47)	−.41 (31)*	−.21 (44)
Prostate cancer	.67 (24)**	.53 (18)*	.56 (21)**
Male digit ratio	−.33 (23)	−.35 (21)	−.12 (20)
Female digit ratio	−.59 (23)**	−.50 (21)*	−.16 (20)
Sex frequency	.08 (41)	.08 (34)	.15 (38)
# Sex partners	.28 (41)	.40 (34)**	.33 (38)*

Note. $^{**}p < .01$; $^{*}p < .05$.

Several of the indicators interacted significantly with intelligence. For example, the CAG repeat length of the androgen receptor gene initially related positively to the number of publications as well as Nobel prizes, contrary to the hypothesis. However, after restricting the analysis to countries with an estimated average IQ higher than 90, this correlation was negatively and significantly related to the science measures. The androgen indicators that did not correlate significantly with the science outcomes often still exhibited substantial effect sizes (≈.30) in the expected direction, which should be interpreted in light of the small sample sizes for some indicators. As such, the overall pattern of findings are in line with the possibility that national average androgen levels are associated with scientific productivity and the probability of producing an individual winning a science Nobel prize, but particularly so when the average IQ is relatively high. Digit ratio tends to stand out from the other androgen indices with substantially lower intra-correlations, even turning to positive ones with androgenic hair (.24) and sex frequency (.33 and .36). This is consistent with digit ratio being and index of prenatal rather than circulating androgens, in effect presumably influencing interests oriented toward science rather than the drive, non-conformism, and competitiveness to pursue them (e.g., Beltz, Swanson & Berenbaum,2011). This is further supported by relatively strong correlations between *publications* and digit ratio (Table 3), even when controlling for a number of other variables (Tables 6 and 7). While it is impossible to determine the specific influence of interests at the present birds-eye level of analysis, this is an important issue for future research.

These findings might contribute to explaining the current global distribution of scientific discoveries and Nobel prizes (Murray, 2003) and can be added to a range of other explanations in the literature that have been advanced to explain this phenomenon, such as national-level differences in general scientific curiosity (Kura et al., 2015), or personality profiles related to scientific discoveries (Dutton et al., 2014). Note that these alternative explanations are not inconsistent with the androgen hypothesis, as androgen levels are related to personality traits (e.g., Herbert, 2015; Zuckerman, 2013). Thus, androgen levels may possibly be one of the more fundamental causes for differences in traits as described in previous research (Dutton et al., 2014; Kura et al., 2015). This is further supported by a large body of research showing that androgens such as testosterone are associated with status seeking and competitiveness (see Herbert, 2015, for a review).

When interpreting the present findings and conclusions various alternative explanations for country-level variation in scientific productivity should be taken into consideration. Obvious examples would be economic prosperity (e.g., GDP) or the level of political freedom (e.g., democracy). It seems evident that such variables affect the opportunities to conduct research, through funding and academic freedoms, while they are not necessarily related to ability and effort. But the deeper theoretical issue is the direction of causality among them and other variables such as population characteristics. Many of the traits dealt with in the present analyses are likely to affect both scientific achievement and wealth, by way of innovations, efficient industrial production, and favorable societal institutions (see Rindermann, 2018; for a review). Similarly, more far-fetched alternative explanations, such as climate temperature (Van de Vliert, 2013) or pathogens (Murray et al., 2011) would conceivably exert their influence through shaping individual characteristics of the population (Van de Vliert & Murray, 2018). This entails theoretical complications that also include the possibility of mastering the environment, so as to reduce pathogens and control temperature by means of proper housing (insulation, central heating, and air conditioning). In accordance with this reasoning, Van de Vliert and Murray (2018), Lynn and Vanhanen (2012), as well as Rindermann (2018) have emphasized the possibility that temperature, pathogens, and the like, may have influenced eventually stable population characteristics that relate to the historical development, and hence the current economic and political systems.

As debates about the causal predominance of various variables (economy, politics, temperature, pathogens, etc.) are still ongoing, we decided it would be useful to also provide information about androgen by science associations after controlling for a composite of such alternative variables. Those analyses revealed that the androgen with publications associations seems to be more robust than the androgen with Nobel prizes associations. One possible explanation for this is that Nobel prizes are given to individuals, thus showing a somewhat more capricious pattern, and awarding them is partly subjective (i.e., is undertaken by a jury). Though journal peer-review also involves subjectivity and caprice, the process is conceivably less subject to favoritism and political and other considerations as it is generally anonymous. Yet, another possible explanation is that Nobel prizes in particular are manifestations of the same underlying factors that also influence economic and political factors, as mentioned above. Thus, controlling for those manifestations would deplete the largest part of the true covariance. In this case, this would imply that the various environmental factors can be considered 'bad controls' (Angrist & Pischke, 2008) that would artificially diminish a true relationship between the androgens indicators and Nobel prizes.

Which of the explanations outlined above one favors cannot be determined on statistical grounds alone, but rather has to been supported theoretically. For example, it can be considered highly implausible that temperature has a direct influence on an individual's length of the androgen receptor CAG repeats, androgenic hair, or 2D:4D ratio (see also Dutton et al., 2016). If there would be any effect on temperature on those variables, it would likely have been mediated through selection (Brumbach, Figueredo & Ellis, 2009; Lynn & Vanhanen, 2012).

Another issue addressed in this study was the origin of the Nobel laureate, which was not always that of the majority of the population of the given country. In general, there were relatively few exceptions and in cases in which the Nobel laureate did not originate from the country's majority group they were often from the same population of those countries that received relatively many Nobel prizes in the first place. As an illustration, Peter Brian Medawar who won the Nobel Prize for Brazil was a Briton and thus originated from a population (UK) that is number six on the list of countries winning Nobel prizes. Similarly, most of the South African Science Nobel laureates originated from the Netherlands, which is number eight on this list. Beyond those specific cases, individuals with an Ashkenazi origin were strongly overrepresented among the Nobel laureates, which are at the same time minorities in many of the countries analyzed. Additional analyses showed that the influence of this exceptional group did not substantially change the androgen by science associations and led to the same conclusions. One may question why the results remain so stable across these quite different groups. The most apparent possibility is that the associations are similar within groups, although individuals with an Ashkenazi descent may differ in absolute levels of the variables relevant to this study. Indeed, the Ashkenazi have higher IQ (e.g., Lynn, 2011), and although findings regarding androgens are less clear and consistent there is some indication that the prevalence of prostate cancer and specific patterns of androgenic hair is relatively high among Ashkenazi men (e.g., Ostrander & Udler, 2008).

In judging the merit of the present findings, it is relevant to point out several possible objections and limitations. The first objection/limitation relates to the so-called ecological fallacy, which states that relations between variables at the group or national level do not necessarily reflect similar associations across individuals. Thus, that higher androgen indicator levels are related to the number of publications across countries or groups in general does not necessarily imply that this holds at the individual level. Although a limitation of the present study is that this point cannot be directly addressed with the current data, we note that several previous studies indicate that similar relationships *do* exist at the individual level. For example, exposure to testosterone was linked to eminence among Polish actors (Karwowski & Lebuda, 2014) and literature Nobel Prize winners (Lebuda & Karwowski, 2016). Moreover, there is a large body of research on the role of androgens on the behavior of individuals, consistent with the present arguments (see Herbert, 2015, for a review).

The second objection is that there may be a third underlying variable that influences most of the variables we included in the present study. For example, it might be proposed that some cultural or economical factor, or even national dietary habits (e.g., the use of dairy products) simultaneously affect science output as well as androgen levels. Even though the presence of such variables always remains a possibility that cannot be excluded, at the end of the day the most plausible explanation has to be determined on theoretical arguments. Economy, culture, and national dietary habits can—and almost certainly will—affect several of the indicators to some extent, such as sexual activity and risk of prostate cancer, independently of androgen levels (Chan et al., 2001). Yet, is it unlikely that indicators such as CAG repeat length and androgenic hair are fully determined by such environmental factors. Rather, our understanding should be built upon consilience across multiple studies and variables, and upon assessing patterns of correlations and interactions, the larger and more specific, the better. This is of course true for the general debate concerning the causal predominance of various indicators, covering a vast amount of studies at the group or national level. Therefore, we can only claim that this first study provides initial support for the hypothesis that the average population androgen level influences the distribution of scientific productivity and Nobel prizes. As such, we hope it will stimulate further inquiry that elaborates on the answers that are still open, such as whether a relationship exists between androgen levels and/or androgen sensitivity and science outcomes at the individual level. Also, future research could take other indicators of scientific excellence or creativity into account such as the *H* index (based on how often researchers are cited) or patents (Karwowski & Lebuda, 2013). All in all, time will tell whether the present findings are in concert with Herbert's (2015) statement that androgens have "...shaped the kind of people we are, the things we invent or prefer, and the kind of society we live in".

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SUPPORTING INFORMATION

Additional supplemental material may be found online in the Supporting Information section at the end of the article:

Table S1. Androgen indicators per country.
Table S2. Extraction of general factor of various combinations of androgen indicators.
Table S3. Correlations between latent androgen factor (various compositions) and science variables.
Table S4. Correlations between latent androgen factor (various compositions) and science variables, after controlling for national-level IQ.