Intelligence 89 (2021) 101584

Contents lists available at ScienceDirect

Intelligence

journal homepage: www.elsevier.com/locate/intell

Domain specific traits predict achievement in music and multipotentiality

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A R T I C L E I N F O

Keywords:
Intelligence
Achievement
Music
Creativity
Expertise
Generalized additive models

A B S T R A C T

Previous research shows that individuals choose careers based on the relative strengths of various traits. More debated however, is how specific combinations of traits predict individual differences in professional achievements. General intelligence is often proposed to be the best predictor of eminence, but some studies suggest that more specific traits can be relatively important when performance depends on specific skills and expertise. Here we identified a comprehensive set of variables relevant for music achievement (intelligence, auditory ability, absolute pitch, Big-five personality traits, psychosis proneness, music flow proneness, childhood environment and music practice), and tested how they predicted level of musicianship (non-musicians vs. amateur musicians vs. professional musicians) and number of achievements among professional musicians. We used web survey data from a total of 2150 individuals, and generalized additive models that can also reveal non-linear relationships. The results largely confirmed our three main hypotheses: (i) non-musicians, amateur musicians, and professional musicians are best differentiated by *domain specific* abilities, personality traits, and childhood factors; (ii) largely the same significant predictors are also associated with the number of creative achievements within professional musicians; (iii) individuals who reach a professional level in two domains (here science and music) possess the union of the relevant traits of both domains. In addition, many of the associations between predictors and achievement were non-linear. This study confirms that in music, and potentially in other occupational fields where performance relies on specific competences, domain relevant characteristics may be better predictors of engagement and creative achievement than broad traits.

1. Introduction

The vast complexity of our civilization has developed in tandem with an ever increasing degree of specialization within essentially every area of society. This diversity in expertise is related to individual differences in personal characteristics such as interests, physical constitution, abilities, personality traits, and values. Fortunately, or as evolution would have it, essentially all physical and psychological traits, including beliefs and values, are a product of nature as well as nurture (Ge, Chen, Neale, Sabuncu, & Smoller, 2017; Plomin, DeFries, Knopik, & Neiderhiser, 2016). Consequently both vocational interests and expertise are the result of an intricate interplay between genetic and environmental factors (Lykken, Bouchard Jr., McGue, & Tellegen, 1993; Ullén, Hambrick, & Mosing, 2016). To give an example, characteristics such as physical constitution, cognitive ability, and personality may determine the probability of success in a particular activity; a negative outcome will typically decrease interest for further attempts while a positive outcome and positive feedback will be rewarding and increase the motivation for continued efforts; thus a process of specialization may begin, which not only involves knowledge and skill acquisition, but also a refinement of the personal characteristics that promoted success in the first place. Accordingly, profile differentiation tends to occur early in life and remain relatively stable into adulthood (Stoll, Rieger, Nagengast, Trautwein, & Rounds, 2021). Lubinski, Benbow and colleagues have in seminal longitudinal studies of precocious youth shown that cognitive abilities and preferences measured at age 13 predict educational outcomes at age 23, occupational outcomes at age 33, as well as creativity and eminence at age 50 (Achter, Lubinski, Benbow, & Eftekhari-Sanjani, 1999; Bernstein, Lubinski, & Benbow, 2019; Wai, Lubinski, & Benbow, 2005). Moreover, these studies also clearly illustrate what was alluded to above, namely that different forms of expertise can be systematically associated with specific combinations of traits or 'trait complexes' (Ackerman & Heggestad, 1997). The results of these studies, along with findings by other researchers, convincingly show that individuals choose academic and professional careers based on their relative strengths of various traits (Pässler, Beinicke, & Hell, 2015; Wai, Lubinski, & Benbow,

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https://doi.org/10.1016/j.intell.2021.101584
Received 17 May 2021; Received in revised form 2 September 2021; Accepted 9 September 2021
Available online 17 September 2021
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2009). Individuals with higher verbal ability, aesthetic values, and interest in organic pursuits (i.e. people vs. things) tend to seek out careers based on education in the humanities while those with higher mathematical and spatial ability, theoretical values, and greater interest in "things versus people" are more inclined to study and work in science, technology, engineering, and mathematics (STEM disciplines) (Bernstein et al., 2019).

All in all, people will generally, based on their own personal profile and opportunities, actively seek out and pursue careers in which they expect to do well, enjoy the work activities, and have colleagues they resonate with on both a professional and personal level. Several theoretical models, collectively labeled person-environment fit models, have been proposed in order to account for the many variables and processes involved in this quest, and have proved useful in applied settings such as vocational counseling and recruitment procedures (Dawis & Lofquist, 1984; Holland, 1997). With reference to such models, researchers have also been able to confirm some straightforward predictions in line with the findings presented above, for instance that the average levels of personality traits vary across occupational groups and that homogeneity is greater within occupations than within organizations (King et al., 2017). That is, two basketball players on different teams are predicted to be more similar to each other (on a range of characteristics) than they are to their respective business managers. Further, job satisfaction is higher when an individual's personality is more similar to the average personality found in that individual's occupation (Gander, Hofmann, & Ruch, 2020; Törnroos, Jokela, & Hakulinen, 2019) and lower if there is a mismatch between an individual's education/skill level and the requirements of an occupation (Flisi, Goglio, Meroni, Rodrigues, & Vera-Toscano, 2017).

Less evident and more debated, however, is the role of domain specific trait complexes when it comes to how individuals can excel *beyond* their peers in terms of professional achievements. Benbow, Lubinski and colleagues, based on the work referenced above, have proposed that trait complexes primarily influence how individuals choose a field of interest. As described above, individuals who choose educations and occupations related to the humanities and social sciences tend to have higher verbal ability relative to mathematical and spatial ability and, conversely, those who select the STEM disciplines tend show the opposite pattern (Kell, Lubinski, Benbow, & Steiger, 2013). However, it is general ability (that is, the latent construct that captures shared variance among cognitive abilities) that is the best predictor of overall occupational attainment, creative output, and eminence, and there is seemingly no threshold beyond which this effect is diminished (Lubinski & Benbow, 2021). This conclusion might be somewhat limited to high ability samples and highly intellectual domains, but there are also studies on more generic samples that suggest that once general ability has been accounted for, specific abilities and personality traits are relatively useless for predicting individual differences in real-life outcomes such as job performance (e.g. Brown, Le, & Schmidt, 2006; Ree, Earles, & Teachout, 1994). These latter findings do not stand uncontested however. There are other studies suggesting that specific abilities *can* account for useful incremental validity beyond general ability, because the association between general ability and achievement is in itself domain specific (de Manzano & Ullén, 2018; Kaufman et al., 2016; Nye et al., 2020); general ability loads more on cognitively varied and demanding tasks (reasoning, problem solving, decision making etc.) and occupational domains obviously differ in this regard (Gottfredson, 1997). de Manzano and Ullén (2018) accordingly showed that an intelligence test was better at predicting creative attainment in science than in the arts, and importantly, that genes associated with intelligence played a greater role in scientific than in artistic attainment. That is, general ability is presumably always beneficial, but in domains where achievement relies heavily on specific cognitive skills and expertise (as for instance in music), the unique contribution of specific abilities (such as auditory ability) and other psychological traits, could prove to be relatively important. The bottom line is that general ability is necessary but not sufficient to explain real-life outcomes in achievement (Eysenck, 1995; Karwowski, Kaufman, Lebuda, Szumski, & Firkowska-Mankiewicz, 2017; Simonton, 1984), and the approach of measuring broad abilities and generic personality traits to find factors that predict achievement across domains has not proved completely satisfactory. An alternative would be to adopt a more domain centered approach, by identifying a cluster of domain relevant traits such as abilities, personality traits, and interests, and subsequently test their predictive value against domain specific achievements. For example, Nye et al. (2020) recently studied a sample of student Navy pilots and showed that specific cognitive abilities such as auditory information processing, spatial orientation, physical dexterity, divided attention, task prioritization, and decision-making, gave sizeable incremental validity beyond general ability to estimates of flight training performance. This demonstrates that unique variance contributed by specific abilities can have predictive value, if the measured abilities are matched to relevant skilled performance outcomes.

In the present investigation, a similar domain centered approach was adopted with music as a model of expertise, to estimate the contribution of various traits to achievement. Creative domains represent good contexts to study achievement for a number of reasons. First, work in creative domains is typically intellectual but at the same time often associated with very specific skill sets, the acquisition of which demands considerable amounts of practice. This provides an interesting setting for studying the role of both more general and specific traits. Second, end products in many creative domains are public, which means that individual productivity can be easily quantified, and the range is theoretically infinite. Third, on a more general level, creativity is important for individuals and crucial for all areas of society, particularly with the current dramatic increase in automation of labor, which increases the demand for jobs and human capital in creative professions that are difficult to automate. There is in fact a rather pressing need to identify and learn more about both personal and cultural factors that promote creative achievement. Here, we addressed this challenge by firstly identifying a comprehensive set of variables relevant for music achievement, and then tested how they jointly predicted attainment (non-musicians vs. amateur musicians vs. professional musicians) and number of achievements among professional musicians. The variables of interest included general and specific abilities (general ability, auditory ability, absolute pitch), broad and specific personality traits (Big-five personality traits, psychosis proneness), music flow proneness, childhood environment (number of musicians and recordings in the home, going to concerts), and total music practice, along with a number of control variables (age, sex, music genre, music occupation). The rational for this selection of variables can be summarized as follows.

Previous research has shown small-to-modest correlations between general ability and amount of music practice (Butković, Ullén, & Mosing, 2015), and music practice is a moderately strong predictor of music achievement (Mosing, Hambrick, & Ullén, 2019). Mosing et al. (2019) also showed a very small direct association between general ability and music achievement ($\beta = 0.067$) when the latter was measured as engagement in music activities/professional attainment. The relations between general ability and music outcomes could however also be driven or moderated by other factors such as auditory ability and openness to experience (Butković et al., 2015; Swaminathan & Schellenberg, 2018; Swaminathan, Schellenberg, & Khalil, 2017). It has been hypothesized that there is a threshold beyond which the effect of intelligence on creativity is attenuated, but findings have been inconsistent and some of the most prominent studies on creative achievement (across domains) have not found such a threshold (e.g. Jauk, Benedek, Dunst, & Neubauer, 2013; Karwowski et al., 2016; Lubinski & Benbow, 2021). The study that arguably comes closest to investigating a non-linear relationship between intelligence and musical creative achievement was de Manzano and Ullén (2018), where we used a large sample ($n = 6606$) to test for non-linearities in the association between intelligence and artistic creative achievement, using polynomial regression.

The association was found to be linear ($\beta = 0.08$), which is consequently what could be expected also for the subdomain of music.

Auditory ability correlates with music practice (Mosing, Madison, Pedersen, Kuja-Halkola, & Ullén, 2014) but it remains unknown if there is in this case a threshold beyond which the musical ear is essentially good enough for reaching any level of achievement. It is also unclear how absolute pitch, which refers to the ability to identify a given musical note without a reference tone, is related to musical achievement.

When it comes to personality and musical expertise, the by far most consistent observation is a moderate relation between openness and musicianship (Kuckelkorn, de Manzano, & Ullén, 2021). What is rarely acknowledged in the literature however, is that items in this scale literally probe about having artistic interests, valuing artistic/aesthetic experiences, and being sophisticated in music (Costa & McCrae, 1992). Since this is part of the definition of a musician in the first place, comparing the "aesthetic sensitivity" of openness between musicians and non-musicians is effectively circular reasoning. In the same way, we commonly think of creative individuals as imaginative, inventive, original, and full of ideas. These attributes are also closely matched with items in the openness scale. Thus, finding differences in openness between those who are, and those who are not working in a creative domain might seem more like testing the validity of a stereotype than providing deep insights into the psychological underpinnings of the creative mind. Nonetheless, beyond such simple comparisons, there are interesting observations to be made. For instance, we have previously showed that even though the level of openness was higher in artists than in scientists (presumably due to higher "aesthetic sensitivity"), the genetic overlap between openness and achievement was similar in the arts and science (63% and 59% respectively) (de Manzano & Ullén, 2018). This could indicate that independent of domain of interest, individuals who enjoy creative thinking and seek out creative professions share a certain genetic predisposition. It has also been shown consistently, that individuals with higher openness tend to perform better at psychometric fluency/divergent thinking tasks (Lane et al., 2009; McCrae, 1987). Interestingly, we further found that the effect of openness on artistic creative achievement was non-linear and increased exponentially throughout the range of the measure, which was not the case for scientific creative achievement. This indicates firstly that non-linear effects should not be ruled out a priori, and secondly that both the magnitude and the shape of the effect can vary between domains (de Manzano and Ullén, 2018).

Regarding other Big-five personality traits related to musicianship, findings have been much more inconsistent, and it remains unclear how important broad personality traits really are for excelling beyond others; one recent larger study showed that professional musicians had higher neuroticism than amateur musicians and non-musicians, and lower consciousness and lower agreeableness than amateur musicians (Kuckelkorn et al., 2021).

Another trait that has been found elevated in musicians is psychosis proneness, particularly positive symptoms (Mason & Daniels, 2018; Wesseldijk, Ullén, & Mosing, 2019) and this seems to apply generally to individuals working in creative professions (Knudsen, Bookheimer, & Bilder, 2019). The direction of causality is indicated by an Icelandic study that showed an association between polygenic risk scores for schizophrenia and bipolar disorder and artistic society membership and working in creative professions (Power et al., 2015). Importantly, however, it remains unclear if individuals with higher psychosis proneness prefer creative professions because of the more liberal culture, increased freedom to structure work routines, and higher acceptance of eccentric personalities, or if the trait is intrinsically related to superior creative performance. There is neuroimaging research indicating that a lower density of thalamic dopamine D2 receptors could be a common denominator for both positive symptoms of psychosis and less inhibited/more creative ideation (de Manzano, Cervenka, Karabanov, Farde, & Ullén, 2010).

Psychological flow can occur during challenging activities in which the difficulty of the task is matched to the skill-level of the person (Nakamura & Csíkszentmihályi, 2009). The flow experience includes high but subjectively effortless attention, a sense of control, loss of self-awareness, an altered experience of time, and enjoyment (Csíkszentmihályi & Nakamura, 2010). Butković et al. (2015) showed that it was specifically the proneness for having such experiences when engaging in musical activities, and not general flow proneness, which predicted music practice. Interestingly, the effect of music flow proneness was found to be almost twice as strong as that of general ability and openness combined. Music flow proneness appears to capture an intrinsic interest or "passion" for music that adds incremental validity when predicting music achievements.

Childhood environment is thought to play a large role in the development of vocational interests and is has been shown that having a musically enriched background is associated with greater engagement in music activities/professional attainment as an adult (Wesseldijk, Mosing, & Ullén, 2019). There is however a lack of research on how such factors measure up when abilities and personality are simultaneously included in the statistical model.

To conclude, many different predictors of music practice and achievement have been investigated, but the present study for the first time brought an unprecedented number of these different factors together to assess their relative significance, firstly in relation to musicianship by comparing non-musicians, amateur musicians, and professional musicians, and secondly (also for the first time) in relation to the number of real-life musical achievements among professional musicians. If person-environment fit would be important not only for choosing a career as a musician, but also for reaching high levels of achievement, we would expect the same factors or cluster of traits to predict outcomes in both these analyses.

More specifically, we predicted both musician groups to score higher than non-musicians on intelligence, auditory ability, openness, neuroticism, psychosis proneness, as well as childhood exposure to music; and that professional musicians would have higher auditory ability, openness, neuroticism, music flow proneness, and psychosis proneness than amateurs, as well as lower conscientiousness. In light of the previously illustrated non-linear relationship between openness and artistic creative achievement, we also wanted to explore non-linearities, not only for openness, but between all predictors and musical creative achievement. As described initially, becoming an expert involves interactions between person and environment, and non-linear effects could appear as a function of reinforcement over time, where good experiences and positive feedback accumulate to accelerate progress, while negative feedback increases the probability for quitting. Also, even if not in the case of intelligence, there might be other traits that are attenuated beyond a certain threshold, so that they are in effect important for becoming a proficient musician, but have less influence on the subsequent accumulation of achievements. Since musical expertise develops in a social context, the amplifying effect of social networks on individual success (e.g. reputation and fame) could also create non-linear associations between relevant traits and achievement (van de Rijt, Kang, Restivo, & Patil, 2014). All in all, there are good reasons to suspect non-linearities and for going beyond the traditional statistical approach of using linear models. Furthermore, if a non-linear relationship should be found, this would importantly warrant more research and extended theory to explain the functional complexity – Why is the effect different, at different levels of the predictor? In addition, we aimed to test for a positive interaction between psychosis proneness and openness. As mentioned, openness describes a person's tendency to be stimulated by art, music, and engage frequently in reflective and creative ideation. Positive symptoms of psychosis on the other hand involve perceptual abnormalities, bizarre experiences, and delusional ideations (Stefanis et al., 2002), which have wide ranging implications for cognition in general. Such aberrations in a person with high openness could consequently influence both artistic experiences and the creative process, potentially enabling artistic output that others find particularly original and interesting, in line with the findings presented above. This begs the question of an interaction between openness and psychosis proneness, with a clear hypothesis about the direction of the effect. One could for instance argue that the psychedelic cat drawings of the artist Louis Wain exemplifies such an interaction. This might not generally characterize artists or musicians, but could help some of them excel beyond their peers in terms of professional achievements. Further, we wanted to test for a positive interaction between music flow proneness and auditory ability. Subjective flow signals optimal performance and is generally an intensely intrinsically rewarding experience. Thus, while high auditory ability implies better performance at a higher level of difficulty, an increased frequency of flow experiences implies more positive feedback that may have a positive influence on practice and help push performance to even greater levels to stay in the "flow channel" and not get bored. In combination, these two traits should therefore accelerate a person to higher levels of musical creative achievement. Consequently, those who have both a "talent" and a "passion" for music would reach exponentially higher levels of achievement.

To explore all these hypotheses, we used Generalized Additive Models (GAM) to test for non-linear associations between the predictors and musical creative achievement, using web survey data from two samples—one large twin cohort and one sample of professional musicians. Given the generally skewed distribution of creative achievement (Carson, Peterson, & Higgins, 2005), the sample of professionals was crucial in order to pad the number of participants with high achievement since previous work indicates that only about 2–10% of individuals in a random sample of the general population actually have a high (professional) level of creative achievement (de Manzano & Ullén, 2018; Roeling, Willemsen, & Boomsma, 2017). Since the web surveys included the Swedish version of the creative achievement questionnaire (CAQ) (de Manzano & Ullén, 2018), which asks participants to report engagement/attainment in seven creative domains (5 artistic and 2 scientific), there was an additional opportunity to address the question of "multipotentiality", i.e. the potential of succeeding in multiple domains, which has traditionally been attributed to high general ability. Lubinski and colleagues have argued that there is no such thing as multipotentiality, given that individuals in different domains tend to have different ability patterns (Lubinski & Benbow, 2021). There are nevertheless individuals who succeed in more than one professional domain. An intuitive explanation based on person-environment fit theories, would be that these individuals possess personal characteristics that in principle represent the union of the trait clusters from each domain. This has however never been demonstrated. Consequently, we decided to compare professional musicians, professional scientists, and professionals working in both domains (ambiprofessionals) with one another, with the hypothesis that scientists would on average have higher general ability, lower auditory ability, and lower openness than musicians and that the ambiprofessionals would match the scientists on general ability, and match the musicians on auditory ability and openness.

2. Methods

2.1. Participants

The data in this study were collected from two different samples that performed the same web survey. Participants in the first sample came from the STAGE twin cohort, which is part of the Swedish Twin Registry (Lichtenstein et al., 2006; Magnusson et al., 2013). Data from this sample were collected between 2012–2013. The web survey included a number of questionnaires and behavioral tests. Participants did not have to finish the entire survey in one go, but could log in several times. There was a certain dropout after each module, which meant that the sample size varied between measures. At maximum, 10,539 twin individuals participated (Mosing, Madison, et al., 2014). For the present study, a subset was created ($N = 6321$) with one randomly selected individual from each complete twin pair combined with all singletons, to account for relatedness in the original sample. Further selection was made according to inclusion criteria that are described in the next section.

The second web survey was targeted at professional musicians, recruited through various Swedish music institutions during 2013–2014. The format was identical to the first survey described above, apart from that an additional specific questionnaire on musical achievements was also included (see next section). At maximum, 582 individuals participated in the survey. Again, further selection was made according to the inclusion criteria (see next section).

Descriptive statistics on the participants can be found in the supplementary Tables S1 and S2.

All included participants gave informed consent and the present study was approved by the Regional Ethical Review Board in Stockholm (Dnr 2011/570-31/5, 2011/1425-31, 2012/1107/32, 2013/1777-32).

2.2. Measures

Musical achievement was defined based on the Swedish adapted version of the Creative Achievement Questionnaire (CAQ), originally developed by Carson and colleagues (2005; de Manzano & Ullén, 2018). This is a self-report questionnaire about engagement and attainment in seven creative domains: visual arts, dance, music, theater, writing, invention, and science. For music, participants choose one of the following levels: (1) I am not at all involved in music; (2) I am self-taught and engaged in music privately, but I have never played, sung, or presented my own music for others; (3) I have taken lessons in music, but I have never played, sung, or presented my own music for others; (4) I have played or sung, or my music has been presented in concerts in my home town, but I have not been paid for it; (5) I have played, or sung, or my music has been presented in concerts in my home town, and I have been paid for it; (6) I am professionally active as a musician; (7) I am professionally active as a musician, and have been reviewed or acknowledged in national Swedish media or international trade press, and/or have received at least one prize or award for my work in music. For this study, this scale was collapsed into three categories: non-musicians, amateurs, and professional musicians, as described below. These categories were chosen to produce more evenly sized and suitable groups with regard to the available samples, and more robust classification.

Since several of the independent variables in this study have previously been found important across many creative domains, we adopted the scoring method from de Manzano and Ullén (2018). This scoring method limits relationships between predictors and achievement in other domains from confounding relationships between predictors and musical achievement. For example, since openness is related to creative achievement in multiple domains it would be difficult to ascertain the specific relationship between openness and musical creative achievement, if participants with higher achievement in other creative domains were included in the analyses (de Manzano & Ullén, 2018). More specifically, a participant was only included in the study if the CAQ score in music was also the highest score across all CAQ domains ($N = 2027$); this score is henceforth referred to as M_CAQ. 'Non-musicians' were defined as individuals who reported (1) not playing an instrument, and (2) had an M_CAQ score of 1. It was also decided to be more stringent about the definition of amateur musicians to make the group be more in line with, arguably, the implicit understanding of the concept. Thus, 'amateur musicians' were considered to be individuals who (1) reported to play a music instrument, (2) had music practice of at least 500 h (separating them from individuals who merely tried an instrument briefly), (3) were still playing a music instrument at the time of the survey, and (4) had an M_CAQ score between 2–4. 'Professional musicians' were defined as (1) individuals who reported 6 or 7 on M_CAQ and (2) were still playing a music instrument at the time of the survey.

Personality was assessed using the Swedish version of the 44-item Big Five Inventory (BFI) (John, Naumann, & Soto, 2008; Zakrisson, 2010), where participants respond to statements by either agreeing or disagreeing on a Likert-scale between 1 and 5. Each item is assumed to load on one of the Big-five personality factors Extraversion (E), Agreeableness (A), Conscientiousness (C), Neuroticism (N), and Openness (O), and scores from items pertaining to each factor are averaged, taking into account that some items are reverse coded.

Psychosis proneness was estimated with the positive dimension of the Community Assessment of Psychic Experiences (CAPE42) (Konings, Bak, Hanssen, van Os, & Krabbendam, 2006; Stefanis et al., 2002). This subscale consists of 20 items where the participants report how often they have certain experiences ("Never", "Sometimes", "Often", "Almost always"). The responses are converted to scores (1–4) and summed up to a single variable (PsyP).

Psychometric intelligence was measured with the Wiener Matrizen Test (WMT) (Formann & Piswanger, 1979). This is a timed (25 min) visuospatial matrix reasoning test that is similar to and correlates with the Raven's Standard Progressive Matrices ($r = 0.92$) (Formann & Piswanger, 1979). The test consists of 24 multiple choice items where correct responses are summed up to give a total score.

Childhood exposure to music was probed with three questions: "How many people in your childhood environment (family, close friends) played a music instrument? Remember that singing counts as an instrument" (Players); "How many recordings of music (e.g. tapes, vinyl, cassettes, CDs) were in your childhood home?" (Records); "How often did you accompany your parents to concerts, theater, or opera as a child?" (Concerts). Responses were given on Likert scales where each step represented a range (e.g. 0, 1–2, 3–5, etc.). The scales had 8, 9, and 4 scale steps respectively.

Auditory ability was measured with the Swedish Musical Discrimination Test (SMDT) (Ullén, Mosing, Holm, Eriksson, & Madison, 2014). The SMDT includes three subtests targeted at pitch, rhythm, and melody discrimination. The pitch test consists of 27 trials where on each trial, the participant has to judge whether the second out of two tones was higher or lower in pitch. In the rhythm test, with 18 trials, the participant has to judge whether the second of two presented rhythms was similar or different to the first. The melody test, which also has 18 trials, presents two melodies on each trial and the participant has to indicate which tone in the second melody deviated from the first. The number of correct responses are first summed and standardized for each subtest, and then these scores are summed to a total test score (Aud).

Absolute pitch was assessed with an online test where participants had to indicate the identity (pitch class) of tones presented for 1 s by clicking on the corresponding pitch label within 3 s. Two sets of tones were used as auditory stimuli during the test. Both were based on the same set of pitches, i.e. all 12 pitches of the chromatic scale selected from a range of two octaves from C4 to B5. Both sets used the same pitches in the same order, but with different timbre: The first set of tones was generated with Kontakt 4 and Bösendorfer grand piano samples, while the second set was comprised of sine waves generated with Audacity. The piano stimuli were presented before the sine waves and had the same pitch sequence. This sequence was a pseudorandomized permutation of the tones that started in the middle of the C scale, had steps larger than 3 semitones, and had no more than 3 consecutive pitches from the same octave (4 or 5). An additional set of 6 tones, alternating between piano tones and sine waves, was created as a practice set and presented before the actual test. Participant responses were given as pitch only (not octave) and coded accordingly on screen (e.g. F#, C, G), presented in a circle. In this study, only the responses to the sine waves were used in order not to have the results confounded by piano expertise. The upper confidence limit for the chance proportion of correct responses was calculated using the binomial Clopper-Pearson exact method based on the beta distribution and $\alpha = 0.05$, and was estimated to 4.56. Hence, a binary variable (AP) was created where participants scoring 5 or more on the 12 sine waves were considered to have absolute pitch.

Total music practice was estimated with a self-report questionnaire. First, participants were asked whether they played an instrument (including singing) or not. Those that reported to play an instrument were subsequently asked to estimate how many hours per week on average they had played or practiced (any) music instruments in 4 age intervals (0–5, 6–11, 12–17, and 18–now). Based on these responses, and their age at the time of the survey, an estimate of total music practice (M-practice) was calculated.

Music flow proneness was measured using the music subscale of the Swedish Flow Proneness Questionnaire (SFPQ) (Ullén et al., 2012). This scale has seven items, each probing a different dimension of the flow experience. Participants rate the frequency of experiencing each dimension on a 5-point Likert scale ("Never" to "Every, or almost every day") and a total sum score is calculated from the seven items (FP-music).

Professional music achievements were measured in the second sample using a novel questionnaire – the Swedish Musical Achievement Questionnaire– with 23 items, where each item represented a category of musical achievements (Wesseldijk, Mosing, & Ullén, 2021). The categories were selected to sample a broad range of achievements, including for instance composition, solo and orchestra performances, and teaching. For each item, participants were asked to report the number achievements within the given category, for instance, the number of produced original compositions, or the number of different musical pieces performed with an orchestra, or the number of taught students that won awards in international competitions. The score for each item was standardized and then all scores were summed up to give a total professional music achievement score (Ach).

Professional music genre (M-genre) was only available in the second sample and determined with a multiple choice question where participants could select between Classical/Western, Jazz, Pop/Rock, Folk, or Other (free text).

Professional occupational genre (O-genre) was only available in the second sample and determined with a multiple choice question where participants could select between Instrumentalist (solo and smaller ensembles), Instrumentalist (orchestra), Singer/Vocalist (solo), Singer/Vocalist (ensemble/choir), Composer, Pedagogue, Other (free text).

3. Data analysis

Several of the included measures, such as intelligence and personality, were continuous measures that are usually found to be normally distributed in the general population. However we also had some more exotic measures where the best methodological approach could be discussed. For instance, childhood exposure to music was represented by three items: Concerts (how frequently concerts were attended as a child) was represented by one item with four Likert scale steps, and would presumably have a right skewed distribution (with most individuals not going to concerts very often and fewer individuals going more frequently). Players had more response alternatives, but would probably also be skewed in the same way as the number of individuals in a household. Records had one more response alternative than Players and might include more noise since remembering music recordings is arguably more difficult. We therefore opted for not creating a composite measure of these variables here and instead modeled the effect of each variable separately.

In addition, in line with what was discussed in the Introduction, there was little reason to assume that every variable of interest should be linearly related to the outcome. Thus, to accommodate all these peculiarities at once, that is, variables of a more ordinal nature, non-normal distributions, and non-linear relations, it was decided to use GAMs as a multivariate framework for testing how each variable was specifically related to achievement. Using a GAM, the effect of an independent variable is captured through a smooth function that can be non-linear, depending on the data. The GAM can be written as $g(E(Y)) = \alpha + s_1(x_1) + \cdots + s_p(x_p)$, where Y is the dependent variable, $E(Y)$ is the expected value, and $g(Y)$ is the link function (e.g. logit) that links the expected value to the independent variables $x_1, \ldots, x_p$. Each smooth term

$s_1(x_1)$, …, $s_p(x_p)$ was here represented by a cubic regression spline. A spline can be thought of as a piecewise cubic polynomial, where the number of pieces is defined by the number of "knots" on the curve. Thus, the approach can be thought of as a general linear model, but instead of estimating one coefficient for every predictor, a set of coefficients are estimated (corresponding to the number of knots) that determine the shapes of basis functions that when summed produce a spline. The spline can thus be fitted to the data by optimizing the coefficients; here this was done according to the restricted maximum likelihood. The initial number of knots has to be set manually and should be large enough to model the reasonably expected non-linearity. The initial number of knots (k) for the splines was here set to $k = 5$ for all relevant (non-categorical) variables, except for the childhood variables where the number of knots was set to the number of response alternatives. In practice, since one knot is reserved for the intercept, the latter procedure allows for a different slope of the effect between each scale step, which was our way of handling the ordinal nature of the childhood scales. The "wiggliness" of the splines were penalized to avoid overfitting by the conventional integrated squared second derivative cubic spline penalty (for details see Wood, 2017). The penalty is a function of the model coefficients (β), and a penalty matrix, which can be written as S. The penalty is then $\beta_T S \beta$. Roughly put, the penalty matrix measures the wiggliness of each basis function, and how the wiggliness of one basis function affects the wiggliness of another. Just as the β scale the individual basis functions, they also scale penalty values in the penalty matrix. The penalty consequently shrinks the estimates of β towards zero, i.e. away from the values they would take if the wiggliness of the smooth was fixed at the initial number of knots. A smoothness parameter λ controls the magnitude of the wiggliness penalty as $\lambda \beta_T S \beta$ is added to the log-likelihood. In the present study we use the default λ, which shows good performance in the trade-off between smoothness of the estimated spline function and the fidelity to the data. More on the technical details of GAMs can be found in Wood (2017).

It should be noted that the p-values associated with the smooth terms are approximate (in the same sense that p-values for a GLM are approximate, e.g. relying on asymptotic behavior) since they are based on the assumption that a penalized fit is equivalent to an unpenalized fit with the same effective degrees of freedom, and they neglect the uncertainty associated with smoothing parameter estimation. Their properties are however good in most instances, especially when the model is estimated with (restricted) maximum likelihood smoothness selection, but p-values that are very close to the statistical threshold (both above and below) should be viewed with some consideration (Wood, 2013). Nevertheless, the GAM approach provides a flexible estimation of the effects without making a priori assumptions about the pattern of the relations. Since the effects in GAMs may vary as non-linear functions of the predictors, it is difficult to provide effect sizes. It is however possible to systematically exclude predictors (while keeping the smoothing parameters of the remaining predictors) and observe how that influences the overall explained deviance. For reference, the deviance explained will be the same as the variance explained (unadjusted) when the errors are Gaussian (deviance is then residual sum of squares, but not otherwise). The difference in deviance between the base model and the reduced model for a certain predictor is henceforth referred to as partial explained deviance (D_p). Note that the partial explained deviance of all predictors will not add up to the total explained deviance if predictors correlate, i.e. if some of the explained deviance is shared between predictors.

All GAMs were performed using the package 'mgcv' (Wood, 2017) in R (R Core Team, 2020). The first main analysis was between the achievement groups. Logistic GAMs were estimated for the pairwise classification of non-musicians, amateurs, and professionals. The classification between amateurs and professionals also included the variables M-practice and FP-music, which were only available in these groups. Two models, with and without the hypothesized interaction between psychosis proneness and creative personality (PsyP:O), were estimated for each pairwise classification. To evaluate the performance of classification, the receiver operating characteristic (ROC) curve was calculated, which corresponds to the true positive rate (sensitivity) presented as a function of the false positive rate (1-specificity). The maximum value of the Youden index (J = sensitivity + specificity – 1) can be used to describe a point on the ROC curve where there is an "optimal" tradeoff between sensitivity and specificity, which in turn can be used to define a threshold for classification. Further, the area under the ROC curve (AUC) is a measure of how well the model can distinguish between the groups, where values between 0.5 and 1 represent a range from chance to perfect classification. The second main analysis, which involved only the professional musicians, consisted of a GAM with professional achievement regressed on the independent variables, including musical and occupational genre as nuisance variables. Again two models, with and without interactions, were estimated. The latter model additionally included the hypothesized interaction between music flow proneness and auditory ability (FP-music:Aud). The third main analysis was performed in order to compare traits between individuals who were musicians, scientists, or both. It was considered necessary to boost the power of this analysis, and we therefore relaxed the inclusion criteria somewhat, counting anyone who had at some point received monetary reimbursement for their musical/scientific performance as a "professional". Thus, a categorical variable was created (C-domain) with professional musicians defined as having a CAQ score in music >4 and a CAQ score in a scientific domain (science or inventions) < 3, professional scientists as having a CAQ score in music <3 and a CAQ score in a scientific domain >4, and ambiprofessionals as having a CAQ score in both domains >4. Using this more relaxed definition for being a professional, the sample included 466 professional musicians, 134 professional scientists, and 58 ambiprofessionals (professional in both domains) who had complete data on all variables of interest, giving a total of 658 participants. A MANOVA was then performed with all non-categorical variables as dependent variables, and with C-domain, age, and sex as predictors. A MANOVA uses the covariance between outcome variables in testing the statistical significance of the mean differences, which helps to account for dependencies between the traits while avoiding the multiple comparisons problem of using multiple ANOVAs. Tukey's HSD post hoc tests were used to achieve the main purpose of this analysis, which was to compare the mean level of each trait between groups. This admittedly abandoned some of the methodological complexity of the previous analyses, but would be enough to confirm/reject the simple hypothesis that the ambiprofessionals match the domain specialists in both music and science on the most relevant traits.

Additional analyses of a more descriptive nature were also performed leading up to the three main analyses. These analyses included descriptive statistics, partial pairwise Pearson product moment correlations between the non-categorical variables adjusting for age and sex, and analyzing mean differences in these variables between the achievement groups. The latter analysis was performed using one-way ANOVAs and Tukey's HSD tests; such methods build on assumptions that disregard some of the complexities discussed above, but were here merely intended as a reference for the more complex main analyses, where achievement was regressed on all independent variables simultaneously.

For all of the above mentioned analyses, the non-categorical variables were standardized. Results are referred to as significant if $p < 0.05$, two-tailed.

4. Results

Descriptive statistics for the participant groups and studied non-categorical variables are provided in Tables S1–S2. A table of correlations between the non-categorical variables, adjusted for age and sex, can be found in Table S3. Table S4 illustrates the frequency of professional musicians within different music genres tabulated across occupational genres.

The one-way ANOVAs, which compared the means of the continuous variables between achievement levels (see Table 1), showed that amateurs scored higher than non-musicians on all variables except for conscientiousness and neuroticism (the latter $p = 0.08$). Professionals scored higher than non-musicians on all variables except extraversion ($p = 0.08$), agreeableness, conscientiousness, and neuroticism. The comparison between professional and amateur musicians gave a more mixed picture. Professionals scored higher than amateurs on age, auditory ability, openness, psychosis proneness, music flow proneness, and music practice, but lower than amateurs on agreeableness. All other comparisons were found non-significant. Thus, the traits that increased significantly for each achievement level in these analyses were auditory ability, openness, psychosis proneness, concerts in childhood, music flow proneness, and music practice. No variable decreased significantly for each achievement level. Fig. 1 illustrates the mean of each significant variable in each participant group.

Fig. 2 shows two spline surfaces fitted to the raw data, corresponding to the two hypothesized interactions between predictors of professional achievements, i.e. between psychosis proneness and openness (panel A), and between auditory ability and music flow proneness (panel B). The graphs imply that there could be synergistic effects and that the interactions should be formally tested (see GAM of professional achievements).

The prevalence of absolute pitch was, compared to the non-musicians, more than two times higher in the amateur musicians and almost 30 times higher in the professional musicians. Further, absolute pitch was about three times more common in males than in females (5.2% vs. 1.8%). Nevertheless, the prevalence in absolute terms was low, particularly in amateurs and non-musicians. It was therefore assumed that this variable would not contribute much to the logistic GAMs and absolute pitch was consequently excluded as a predictor in these analyses. Table 2 displays the prevalence of absolute pitch at each level of achievement.

4.1. *Logistic GAM of amateur musicians and non-musicians*

Table 3 shows the results of the logistic GAM of amateurs and non-musicians, i.e. the effects of the smooth terms (A) and parametric coefficients (B). The adjusted R^2 was 0.59 and the total deviance explained was 54.7%. The classification accuracy at Youden's J was 86.5% and the AUC was 0.94. Note that an estimated degrees of freedom equal to 1 means that the smooth term has been penalized to a linear relationship, while a value greater than 1 indicates a non-linear relationship (a wigglier spline uses more degrees of freedom). For a linear relationship, the level of the dependent variable will be a linear function of the independent variable (illustrated as a straight line with a certain slope corresponding to the size of the effect). For a non-linear relationship, the size of the effect will change as a smooth function of the independent variable, and the estimated degrees of freedom will indicate the degree of complexity. This can be observed in Fig. 3, which visualizes the smooth terms of each significant variable of interest (i.e. the significant partial effects). Being an amateur musician as compared to a non-musician was associated with higher intelligence, auditory ability, agreeableness, neuroticism, openness, psychosis proneness, music players in childhood, concerts in childhood, and female sex. The by far largest effects were found for auditory ability, openness, and concerts in childhood. These variables also contributed the highest partial explained deviance. Several effects were non-linear but with a reasonably low level of complexity, as indicated by the effective degrees of freedom and illustrated by the modest wiggliness of the smooth functions in Fig. 3. Auditory ability stands out as particularly interesting, as its effect appears to increase exponentially throughout the range of the measure. There were no effects of age, conscientiousness, or recordings in childhood. The interaction between psychosis proneness and openness was not found significant in the extended model (see Table S5) and AUC and classification accuracy were identical to the original model.

4.2. *Logistic GAM of professional musicians and non-musicians*

During model checking it was found that the initial number of knots for age should be increased to improve estimation, which would however also increase the risk of overfitting the data. Since age was not a variable of interest, it was deemed more important to adjust for potential non-linearities, for instance due to uneven sampling, than to maximize the generalizability of this partial effect. The knots parameter for age was therefore increased to an arbitrary high value (30), to ensure a sufficient number of knots, and leave it to the regularization to bring this number down to the effective degrees of freedom. As pointed out in the Methods, the exact initial value is not particularly important as long as it is large enough. Table 4 shows the results of the logistic GAM of professionals and non-musicians, with effects of the smooth terms (A) and parametric coefficients (B). The adjusted R^2 was 0.98 and the total deviance explained was 97.5%; classification accuracy at Youden's J was 99.7% and the AUC was 1.0. A visualization of the significant smooth terms of interest (partial effects) can be found in Fig. 4. Higher auditory ability, conscientiousness, openness, psychosis proneness, concerts in childhood and lower extraversion helped distinguish professional musicians from non-musicians. The effects of auditory ability

Table 1
Results from the one-way ANOVAs.

	F	p-value	η_p^2	p-value NM vs A	p-value NM vs P	p-value A vs P
Age	66.6	**<0.001**	0.058	0.093	**<0.001**	**<0.001**
WMT	90.3	**<0.001**	0.080	**<0.001**	**<0.001**	0.453
Aud	690.8	**<0.001**	0.397	**<0.001**	**<0.001**	**<0.001**
E	8.6	**<0.001**	0.008	**<0.001**	0.080	0.593
A	11.8	**<0.001**	0.011	**<0.001**	0.567	**0.023**
C	1.6	0.209	0.001	0.975	0.223	0.238
N	2.4	0.092	0.002	0.085	0.315	0.991
O	614.0	**<0.001**	0.364	**<0.001**	**<0.001**	**<0.001**
PsyP	40.9	**0.000**	0.037	**0.000**	**0.000**	**<0.001**
Players	262.7	**<0.001**	0.197	**<0.001**	**<0.001**	0.915
Records	56.8	**<0.001**	0.050	**<0.001**	**<0.001**	0.135
Concerts	186.2	**0.000**	0.148	**<0.001**	**<0.001**	**<0.001**
FP-music	101.2	**<0.001**	0.064	–	–	**<0.001**
M-practice	940.0	**<0.001**	0.387	–	–	**<0.001**

Significant p-values are displayed in bold font.
NM = non-musicians, A = amateur musicians, P = professional musicians, WMT = Wiener Matrizen Test (intelligence), Aud = auditory ability, E = extraversion, A = agreeableness, C = conscientiousness, N = neuroticism, O = openness, PsyP = psychosis proneness, Players = number of players of music instruments in childhood environment, Records = number of music recordings in childhood home, Concerts = frequency of attending concerts as a child, FP-music = flow proneness during musical activities, M-practice = total music practice.

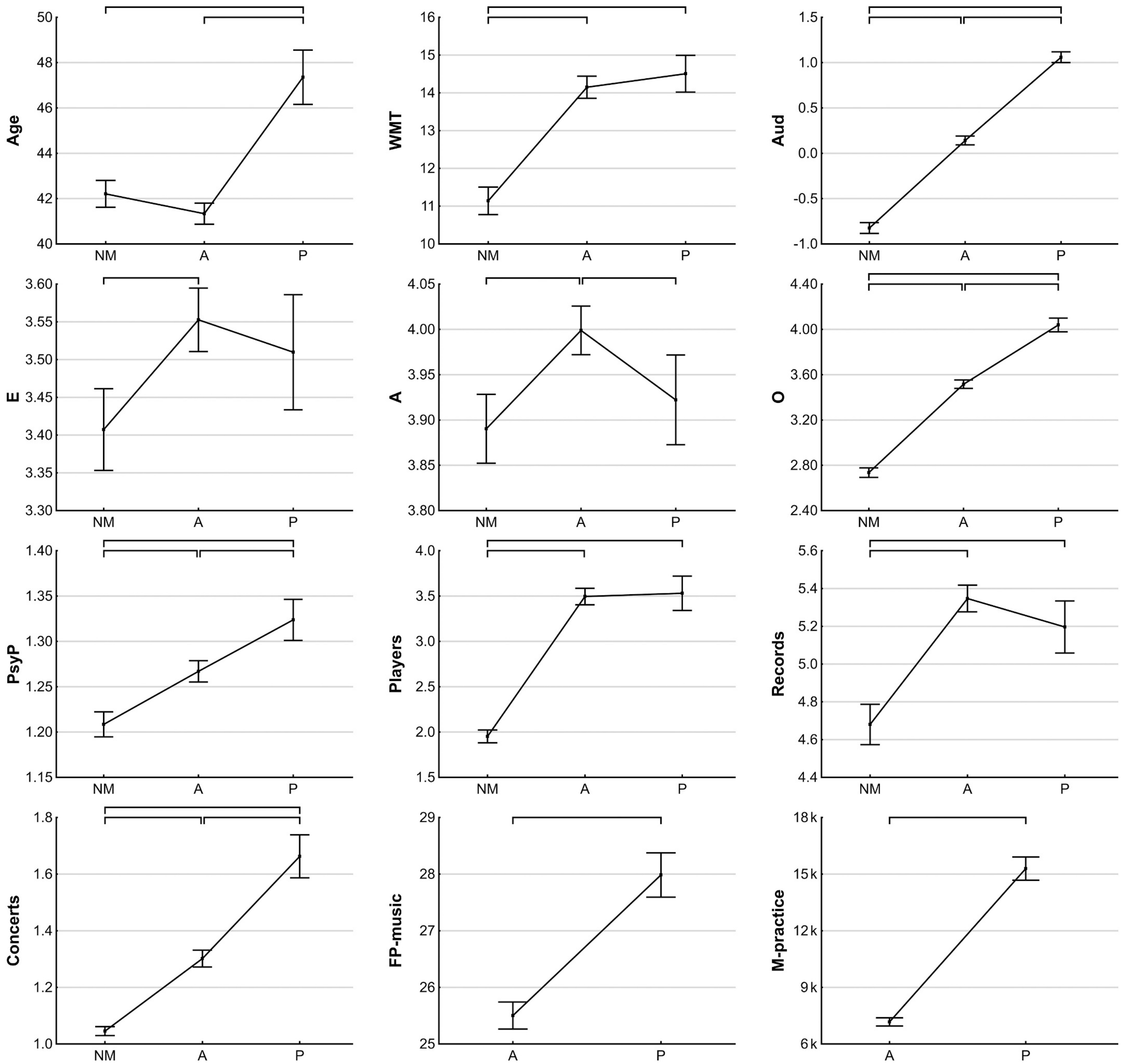

Fig. 1. Means of significant variables from the one-way ANOVAs plotted against achievement level. Error bars indicate 95% confidence intervals of the means. x-axis: NM = non-musicians, A = amateur musicians, P = professional musicians; y-axis: WMT = Wiener Matrizen Test (intelligence), Aud = auditory ability, E = extraversion, A = agreeableness, O = openness, PsyP = psychosis proneness, Players = number of players of music instruments in childhood environment, Records = number of music recordings in childhood home, Concerts = frequency of attending concerts as a child, FP-music = flow proneness during musical activities, M-practice = total music practice.

and extraversion were non-linear. Variables not already mentioned had no significant effects. The interaction between psychosis proneness and openness was not found to be significant in the extended model (see Table S6). AUC and classification accuracy were identical to the original model.

There was some worry that the extremely high classification accuracy would be a sign of overfitting, i.e. fitting too many smooth functions too close to the present data and thereby reducing generalizability Therefore, we firstly explored increasing the level of penalization (gamma = 1.4, in accordance with Wood (2017)). This model produced similar results with an explained deviance of 96.8%. Secondly, the two largest differences between the groups were found for auditory ability and openness, which were both in the range of two standard deviations higher in the professional musicians. We therefore decided to explore an additional model with only auditory ability and openness as predictors. This model explained no less than 87.5% of the deviance, with a similarly modest non-linear association for auditory ability (*edf* = 2.6) and a linear association for openness (*edf* = 1). All in all, these explorations suggest that overfitting was not an issue, and that classification was indeed fairly trivial.

4.3. *Logistic GAM of professional musicians and amateur musicians*

Also in this model, the number of knots for Age was increased (to 30)

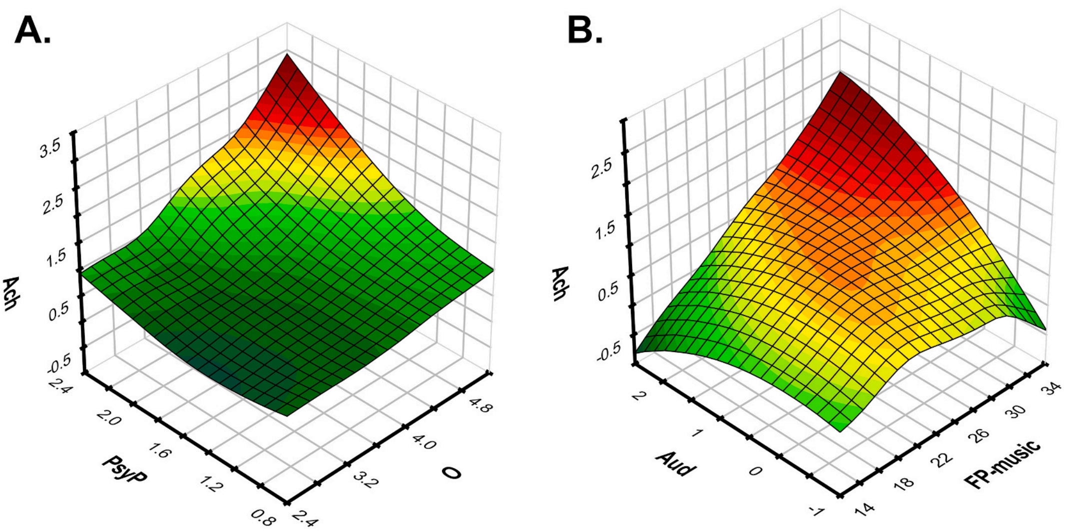

Fig. 2. Spline surfaces illustrating interactions between predictors of professional musical achievements. Panel A – Achievement (Ach) plotted against psychosis proneness (PsyP) and openness (O). Panel B – Achievement plotted against auditory ability (Aud) and music flow proneness (FP-music).

Table 2
The frequency and proportion of individuals with absolute pitch at each level of achievement.

	NM	A	P
AP 0	627	1118	310
AP 1	2	7	29
% with AP	0.32	0.63	9.35

AP 0 = without absolute pitch, AP 1 = with absolute pitch. NM = non-musicians, A = amateur musicians, P = professional musicians.

Table 3
Results of the logistic GAM of amateurs and non-musicians.

A. Smooth terms					
	edf	X^2	D_p (%)	*p*-value	
Age	1.0	0.0	0.0	0.993	
WMT	2.2	15.8	0.8	**0.001**	
Aud	2.8	129.9	7.9	**<0.001**	
E	2.5	6.3	0.4	0.094	
A	1.0	4.5	0.2	**0.034**	
C	1.0	1.2	0.1	0.277	
N	1.0	5.5	0.2	**0.019**	
O	1.4	169.9	10.2	**<0.001**	
PsyP	1.0	6.4	0.3	**0.012**	
Players	2.7	134.6	8.0	**<0.001**	
Records	3.6	9.5	0.6	0.069	
Concerts	1.0	7.9	0.4	**0.005**	
B. Parametric coefficients					
	Estimate	*SE*	*z*-value	D_p (%)	*p*-value
Sex(f)	0.71	0.17	4.2	0.8	**<0.001**

Significant *p*-values are displayed in bold font.
edf = estimated degrees of freedom, D_p = partial explained deviance, WMT = Wiener Matrizen Test (intelligence), Aud = auditory ability, E = extraversion, A = agreeableness, C = conscientiousness, N = neuroticism, O = openness, PsyP = psychosis proneness, Players = number of players of music instruments in childhood environment, Records = number of music recordings in childhood home, Concerts = frequency of attending concerts as a child.

to improve estimation. Table 5 shows the results of the logistic GAM of professionals and non-musicians, with effects of the smooth terms (A) and parametric coefficients (B). The adjusted R^2 was 0.54 and the total deviance explained was 52.2%; classification accuracy at Youden's *J* was 88.0% and the AUC was 0.94. A visualization of the significant smooth terms of interest (partial effects) can be found in Fig. 5. Intelligence and music recordings in childhood had slight inverted U-shaped effects while music players in childhood showed the opposite relation. Extraversion, agreeableness, and neuroticism had negative linear effects while auditory ability, openness, psychosis proneness, and concerts in childhood had positive linear effects. Auditory ability stood out as the variable of main importance in the classification. The high effective degrees of freedom and possibly significance of age could upon closer inspection be attributed to a small number of professional musicians with high age and high achievement who exerted high leverage on the smooth function. Variables not mentioned had no significant effects. The interaction between psychosis proneness and openness was not found significant in the extended model (see Table S7). AUC was identical to the original model and classification accuracy was 0.4% lower.

4.4. GAM of professional music achievements

Since the distribution of professional music achievements was skewed to the right (see Table S2), a log link was used in the GAM. Table 6 displays the outcomes of the GAM where professional music achievements was regressed on all independent variables, with effects of the smooth terms (A) and parametric coefficients (B). The adjusted R^2 was 0.58 and the total deviance explained was 64.9%. A visualization of the significant smooth terms of interest (partial effects) can be found in Fig. 6. As can be observed from Table 6 and Fig. 6, many of the effects were non-linear. In brief, higher psychosis proneness, concerts in childhood, music flow proneness, music practice, as well as male sex, were related to higher number of achievements. Auditory ability, music players in childhood, and recordings in childhood, had more complex non-linear relationships with the outcome. Intelligence had a negative association with achievement. Variables not already mentioned had no significant effects. The extended model showed both interactions to be significant (see Table S8), i.e. between psychosis proneness and openness (*edf* = 2.7, $F = 4.5$, $p = 0.004$) and between music flow proneness and auditory ability (*edf* = 1, $F = 15.8$, $p < 0.001$). This model had an adjusted R^2 of 0.62 and a total deviance explained of 68.8%.

4.5. Trait prerequisites of versatility across creative domains

The results of the MANOVA showed a significant effect of creative domain $F_{(26, 1178)} = 22.5$, $p < 0.001$, Wilk's $\Lambda = 0.45$, partial $\eta_p^2 = 0.33$. Fig. 7 illustrates the group means and significant differences between the groups as determined by the post hoc tests. Scientists and

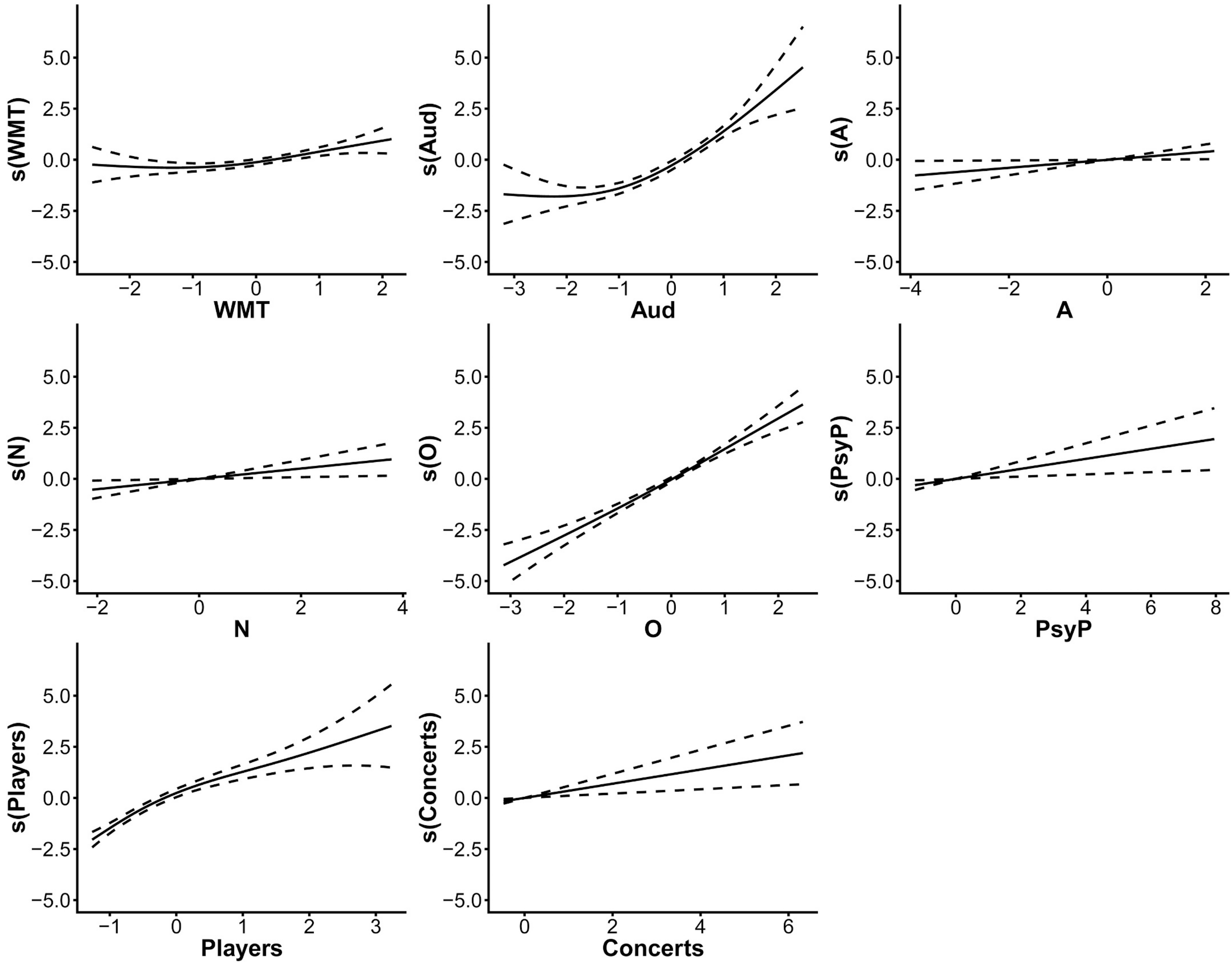

Fig. 3. Logistic GAM of amateur musicians and non-musicians – visualization of the significant smooth functions. The partial effect is represented as a smooth function of the independent variable on the y-axis. WMT = Wiener Matrizen Test (intelligence), Aud = auditory ability, A = agreeableness, N = neuroticism, O = openness, PsyP = psychosis proneness, Players = number of players of music instruments in childhood environment, Concerts = frequency of attending concerts as a child.

ambiprofessionals scored higher than musicians on the intelligence test ($p < 0.001$); musicians and ambiprofessionals scored higher than scientists on openness ($p < 0.001$), Aud ($p < 0.001$), music players in childhood ($p = 0.003$), music flow proneness ($p < 0.001$) and music practice ($p < 0.001$). Further, musicians scored higher than scientists on neuroticism ($p < 0.048$), concerts in childhood ($p < 0.001$), and psychosis proneness ($p < 0.001$); for these latter variables, the ambiprofessionals had scores that fell between the musicians and scientists without differing significantly from either. For openness, the ambiprofessionals also had higher scores than the musicians ($p < 0.02$).

5. Discussion

5.1. Classification of non-musicians, amateur musicians, and professional musicians

In this study we postulated three main hypotheses. The first hypothesis was that non-musicians, amateur musicians, and professional musicians can be distinguished from each other based on domain relevant abilities, personality traits, and childhood factors that increase the probability for engaging and succeeding in music. The present investigation brought these independent variables together and tested their partial and total effects in the most comprehensive multivariate analysis on musical creative achievement to date. The logistic GAMs confirmed the first hypothesis and further showed that auditory ability, openness, proneness for positive symptoms of psychosis, and going to music concerts as a child, were consistently significant in all classifications between the three groups, with professionals scoring higher on all these variables than amateurs, who in turn scored higher than non-musicians. Thus, the multivariate analyses demonstrated the unique contribution of these traits and environmental variables in respect to one another and in relation to the other included variables. Furthermore, the use of GAMs revealed that the effect of auditory ability in classifying between non-musicians and either musician group was approximately exponential. This is an interesting new finding, since previous research has largely ignored the possibility of non-linear relationships, except for a small number of studies on the threshold hypothesis of intelligence, which is discussed below. An exponential effect of domain relevant specific abilities could be one important key to explaining how individuals develop certain vocational interests and commit to a specific domain of interest. It is conceivable that such a non-linear effect could appear as a function of positive reinforcement over time, or rather, as a

Table 4
Results of the logistic GAM of professional musicians and non-musicians.

A. Smooth terms					
	edf	*X2*	D_p (%)	*p*-value	
Age	5.0	8.3	3.9	0.227	
WMT	1.0	0.2	1.9	0.687	
Aud	3.0	16.5	19.5	**0.001**	
E	2.0	7.6	2.8	**0.034**	
A	1.0	0.3	2.0	0.580	
C	1.0	5.1	2.2	**0.024**	
N	2.2	2.0	2.1	0.419	
O	1.0	14.5	10.5	**<0.001**	
PsyP	1.0	8.7	2.4	**0.003**	
Players	4.2	7.8	3.9	0.110	
Records	3.9	6.4	2.8	0.241	
Concerts	1.0	6.1	2.6	**0.014**	
B. Parametric coefficients					
	Estimate	*SE*	*z*-value	D_p (%)	*p*-value
Sex(f)	−2.47	1.28	−1.9	2.2	0.054

Significant *p*-values are displayed in bold font.
edf = estimated degrees of freedom, D_p = partial explained deviance, WMT = Wiener Matrizen Test (intelligence), Aud = auditory ability, E = extraversion, A = agreeableness, C = conscientiousness, N = neuroticism, O = openness, PsyP = psychosis proneness, Players = number of players of music instruments in childhood environment, Records = number of music recordings in childhood home, Concerts = frequency of attending concerts as a child.

function of performances, where in this case higher auditory ability led to more success and more positive feedback, which in turn provided more incentive for acquiring greater skills and for choosing music as a profession. This maps on to the description of how trait complexes develop (Ackerman & Heggestad, 1997). Social feedback, which is discussed further in relation to professional achievements, is another important factor that can inflate effects (van de Rijt et al., 2014). In a cross-sectional analysis, the temporally extended conditional process of reinforcement, and interplay between ability, environment, and interests, would be projected in two-dimensions as a non-linear (accelerating) positive effect, which might explain the effect of auditory ability on achievement.

General ability appeared to have less of a unique effect on the level of musicianship. In the univariate analysis, general ability (as measured by the WMT) was clearly higher in the musician groups than in the non-musicians. This difference was presumably in part a consequence of the process of participant selection, which involved finding a control

Table 5
Results of the logistic GAM of professional musicians and amateur musicians.

A. Smooth terms					
	edf	*X2*	D_p (%)	*p*-value	
Age	10.1	68.9	11.3	**<0.001**	
WMT	2.6	11.1	0.9	**0.011**	
Aud	1.0	159.0	16.3	**<0.001**	
E	1.0	9.1	0.6	**0.003**	
A	1.0	3.9	0.3	**0.049**	
C	2.1	3.3	0.2	0.378	
N	1.0	4.8	0.3	**0.028**	
O	1.0	53.2	3.8	**<0.001**	
PsyP	1.0	12.8	0.8	**<0.001**	
Players	3.0	10.6	0.8	**0.029**	
Records	3.9	21.2	1.7	**0.001**	
Concerts	1.0	49.4	3.6	**<0.001**	
B. Parametric coefficients					
	Estimate	SE	*z*-value	D_p (%)	*p*-value
Sex(f)	−0.30	0.21	−1.5	0.1	0.143

Significant *p*-values are displayed in bold font.
edf = estimated degrees of freedom, D_p = partial explained deviance, WMT = Wiener Matrizen Test (intelligence), Aud = auditory ability, E = extraversion, A = agreeableness, C = conscientiousness, N = neuroticism, O = openness, PsyP = psychosis proneness, Players = number of players of music instruments in childhood environment, Records = number of music recordings in childhood home, Concerts = frequency of attending concerts as a child.

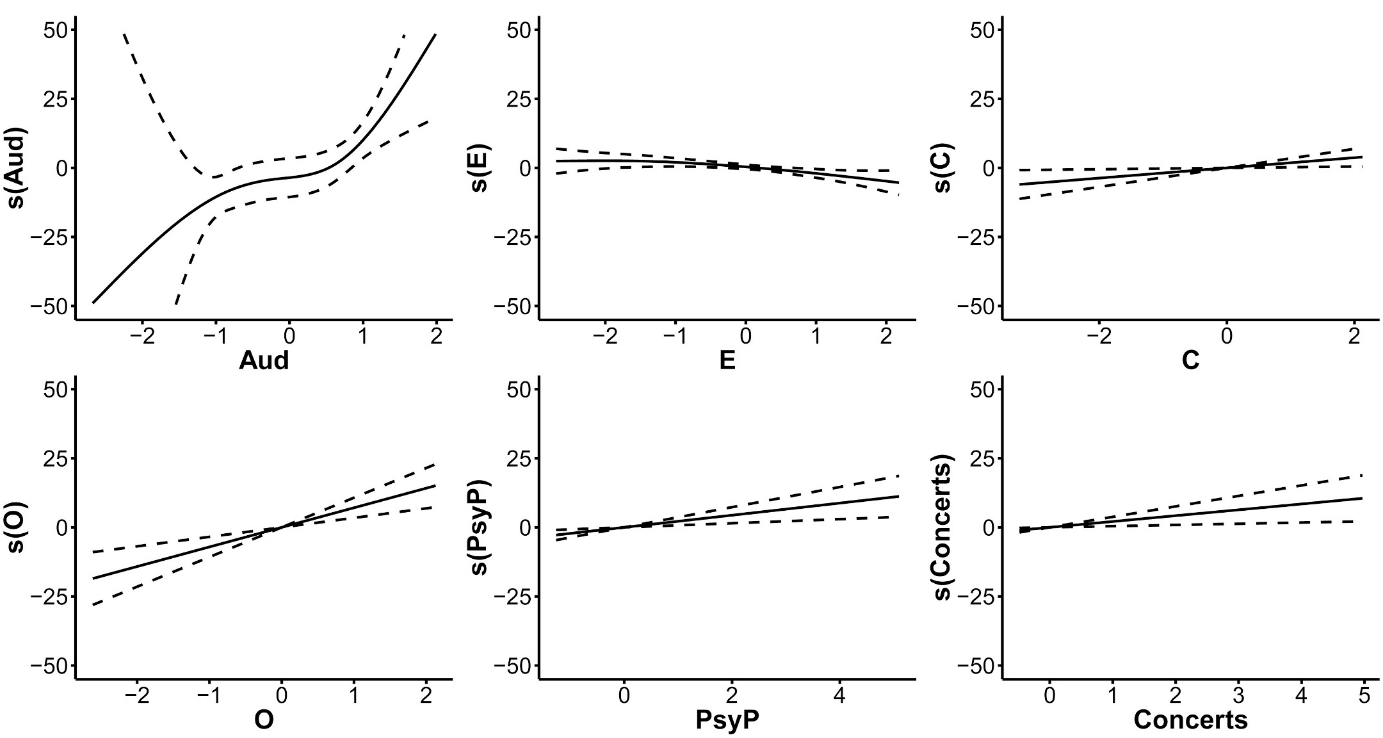

Fig. 4. Logistic GAM of professional musicians and non-musicians – visualization of the significant smooth functions. The partial effect is represented as a smooth function of the independent variable on the y-axis. Aud = auditory ability, E = extraversion, C = conscientiousness, O = openness, PsyP = psychosis proneness, Concerts = frequency of attending concerts as a child.

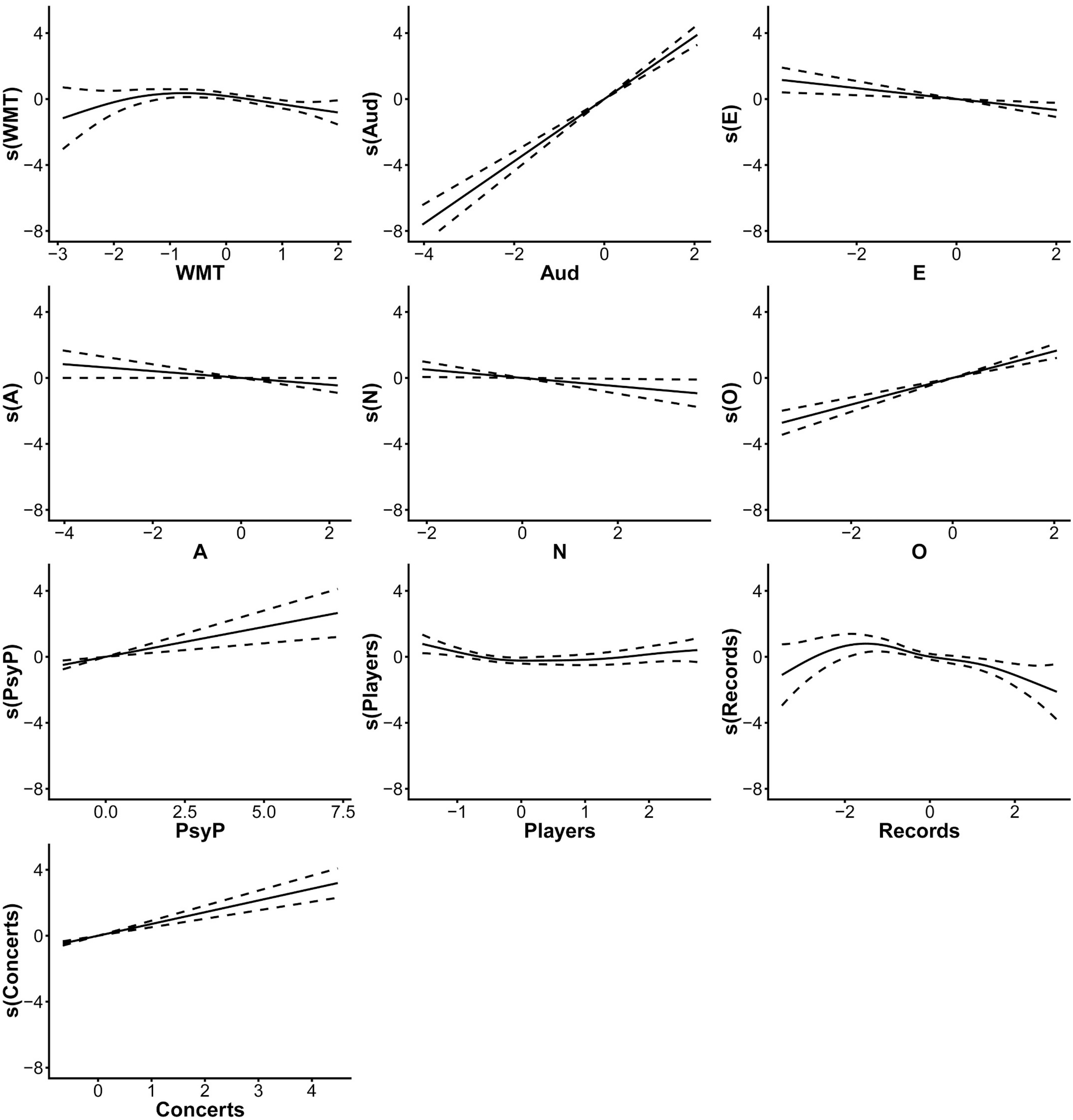

Fig. 5. Logistic GAM of professional musicians and amateur musicians - visualization of the significant smooth functions of interest. The partial effect is represented as a smooth function of the independent variable on the y-axis. WMT = Wiener Matrizen Test (intelligence), Aud = auditory ability, E = extraversion, A = agreeableness, N = neuroticism, O = openness, PsyP = psychosis proneness, Players = number of players of music instruments in childhood environment, Records = number of music recordings in childhood home, Concerts = frequency of attending concerts as a child.

group of non-musicians who did not have notable achievements in any other creative domain either, in order not to confound the data of more domain general traits such as openness (see Methods). That is, the group of non-musicians defined in this analysis would presumably not be representative of non-musicians with creative achievements in other domains, since the latter group would be expected to have higher average scores on relevant domain general traits such as intelligence and openness. For this group, creative achievements in other domains would confound the importance of domain general traits in relation to specifically musical creative achievement, which is why they were excluded.

In the logistic GAMs, the effects of general ability were found to be more complex than suggested by the univariate analysis, and non-significant between professional musicians and non-musicians, even though these two groups had the largest mean difference in general ability raw scores. It seems that much of the variance that could be explained by the WMT was shared with other weakly correlated

Table 6
Results of the GAM of professional musical achievements regressed on personal characteristics, childhood exposure to music, and practice.

A. Smooth terms					
	edf	F	D_p (%)	*p*-value	
Age	3.2	4.0	2.5	**0.014**	
WMT	1.0	4.4	0.7	**0.037**	
Aud	2.8	4.5	2.5	**0.004**	
E	1.0	1.4	0.3	0.236	
A	1.0	3.4	0.6	0.068	
C	1.0	1.5	0.3	0.221	
N	2.5	0.9	0.7	0.413	
O	1.9	2.2	1.0	0.086	
PsyP	2.5	7.3	3.5	**<0.001**	
Players	2.2	2.8	1.6	**0.038**	
Records	5.8	3.9	4.8	**0.001**	
Concerts	1.9	7.2	2.1	**0.001**	
FP-music	1.9	4.5	2.0	**0.009**	
M-practice	1.2	5.8	1.3	**0.016**	
B. Parametric coefficients					
	Estimate	SE	*z*-value	D_p (%)	*p*-value
Sex(f)	−0.27	0.05	−4.9	4.0	**<0.001**
AP	0.08	0.08	1.1	0.2	0.284
M-genre2	0.25	0.08	3.3	5.8	**0.001**
M-genre3	0.23	0.06	3.5	″	**0.001**
M-genre4	0.35	0.09	3.7	″	**<0.001**
M-genre5	0.29	0.06	4.9	″	**<0.001**
O-genre2	0.01	0.08	0.1	2.0	0.908
O-genre3	0.14	0.10	1.3	″	0.181
O-genre4	−0.16	0.16	−1.0	″	0.326
O-genre5	0.06	0.11	0.5	″	0.622
O-genre6	−0.11	0.06	−1.8	″	0.070
O-genre7	−0.13	0.07	−1.8	″	0.077

Significant *p*-values are displayed in bold font.
edf = estimated degrees of freedom, D_p = partial explained deviance, WMT = Wiener Matrizen Test (intelligence), Aud = auditory ability, E = extraversion, A = agreeableness, C = conscientiousness, N = neuroticism, O = openness, PsyP = psychosis proneness, Players = number of players of music instruments in childhood environment, Records = number of music recordings in childhood home, Concerts = frequency of attending concerts as a child. FP-music = flow proneness during musical activities, M-practice = total hours of music practice, AP = absolute pitch, M-genre = music genre, O-genre = occupational genre.

variables such as auditory ability, openness, and childhood exposure to music. This is of course the defining feature of general ability, but in practice, it turned out that the domain specific measures had more predictive value than the general ability measure. It can be noted that we did not use a battery of cognitive ability tests to estimate a latent *g* factor, but instead opted for the common and broadly accepted approach of using a valid measure of fluid reasoning (*Gf*) as a proxy for *g*. Given the generally high external validity of this approach (Gustafsson, 1984), it appears unlikely that using a more comprehensive test battery would have yielded qualitatively different outcomes. In music, information processing and expertise is very much centered on the auditory system. Since skill acquisition is a process of specialization and broad transfer of skills is a rare commodity (Mosing, Madison, Pedersen, & Ullén, 2016; Sala & Gobet, 2017), it might make sense that domain specific traits should be favored in music. By contrast, general ability has more predictive power in science than in the arts (de Manzano & Ullén, 2018; Kaufman et al., 2016), presumably since information processing and creative thinking in science is not in the same way tied to a specific sensory modality or certain narrow abilities, and creative strategies are less reliant on free association (in one modality) and instead more on effortful deliberation. We will return to these domain differences when discussing psychosis proneness in artists and scientists further on.

In line with previous research, higher neuroticism helped identify amateur musicians from non-musicians (Kuckelkorn et al., 2021), but no similar effect was found in the classification between professionals and non-musicians. In contrast to expectations, lower neuroticism identified professionals from amateurs. The latter two findings could have been related to the effect of psychosis proneness, which was higher in the professional musicians. The initial analysis displayed a weak correlation between psychosis proneness and neuroticism and it might be that controlling for the effect of psychosis proneness revealed a negative relation between neuroticism and professional attainment. A similar case can be made for extraversion and conscientiousness. Contrary to the univariate analysis, the logistic GAMs showed that lower extraversion helped identify professional musicians from both amateurs and non-musicians. Extraversion was correlated with openness (r = 0.25) and it would seem that once the high openness of professional musicians was controlled for, extraversion was actually lower in this group. Similarly, higher conscientiousness helped identify professional musicians from non-musicians in the GAM, even though the univariate analysis indicated the opposite direction of effects. Agreeableness instead behaved according to previous findings (Kuckelkorn et al., 2021); higher agreeableness helped distinguish amateur musicians from members of the other two groups, and the smooth functions were linear.

With regard to childhood exposure to music, the number of players in the home environment had a significant effect on the identification of amateur musicians from professionals and non-musicians. Considering the corresponding univariate result, it is not unthinkable that the effect on classification between professionals and non-musicians could have been significant with a larger group of professionals. The number of music recordings in the childhood home had different effects in the different classifications, which makes the interpretation difficult. The differences could be related to the ordinal nature of the item and noise (e.g. uncertainty of retrospective estimates). In any case, it is clear that going to concerts was the childhood variable that best distinguished different levels of musicianship. While for instance the effect of music players and recordings in childhood might be attenuated beyond certain numbers, each live concert might give a powerful impression of what it actually means to be a performing musician, and may help create role models and dreams of similar achievement (Gabrielsson, 2011), which are potentially reinforced at each event. Importantly, it should also be considered that it is generally very difficult to make children of any age obediently endure circumstances they find intrinsically unenjoyable (a product of both nature and nurture), by which they often respond by creating socially awkward situations that parents rather avoid. Therefore, concerts in childhood might capture musical interests of both the parents and the child, and reflect passive as well as active exposure to music.

5.2. Predictors of professional achievements

The second hypothesis stated that the same predictors that were most relevant for classifying between levels of musicianship should also be associated with the number of musical achievements *within* the group of professional musicians. The number of professional achievements in different areas (compositions, performances, recordings, awards, jury positions, students, etc.) were self-reported and the sum of all these achievements was used as the outcome measure, and the analysis was adjusted for musical and occupational genre. Again using a GAM, the second hypothesis was largely confirmed in that auditory ability, psychosis proneness, and concerts in childhood were all significantly related to accumulated achievements. Remarkably, psychosis proneness had a pronounced, approximately exponential effect on the number of achievements and showed the strongest effect overall. The relative strength of this effect was surprising, although an association was expected. There is a growing body of literature indicating that certain forms of mental illness, or proneness for certain aberrant cognition is related to creative achievement. Some of the more convincing evidence includes research by Power et al. (2015), who found, and replicated in three large independent samples, that polygenic risk scores for schizophrenia and bipolar disorder predicted creative achievement (attainment in a creative domain); Kyaga et al. (2013) studied a sample of more

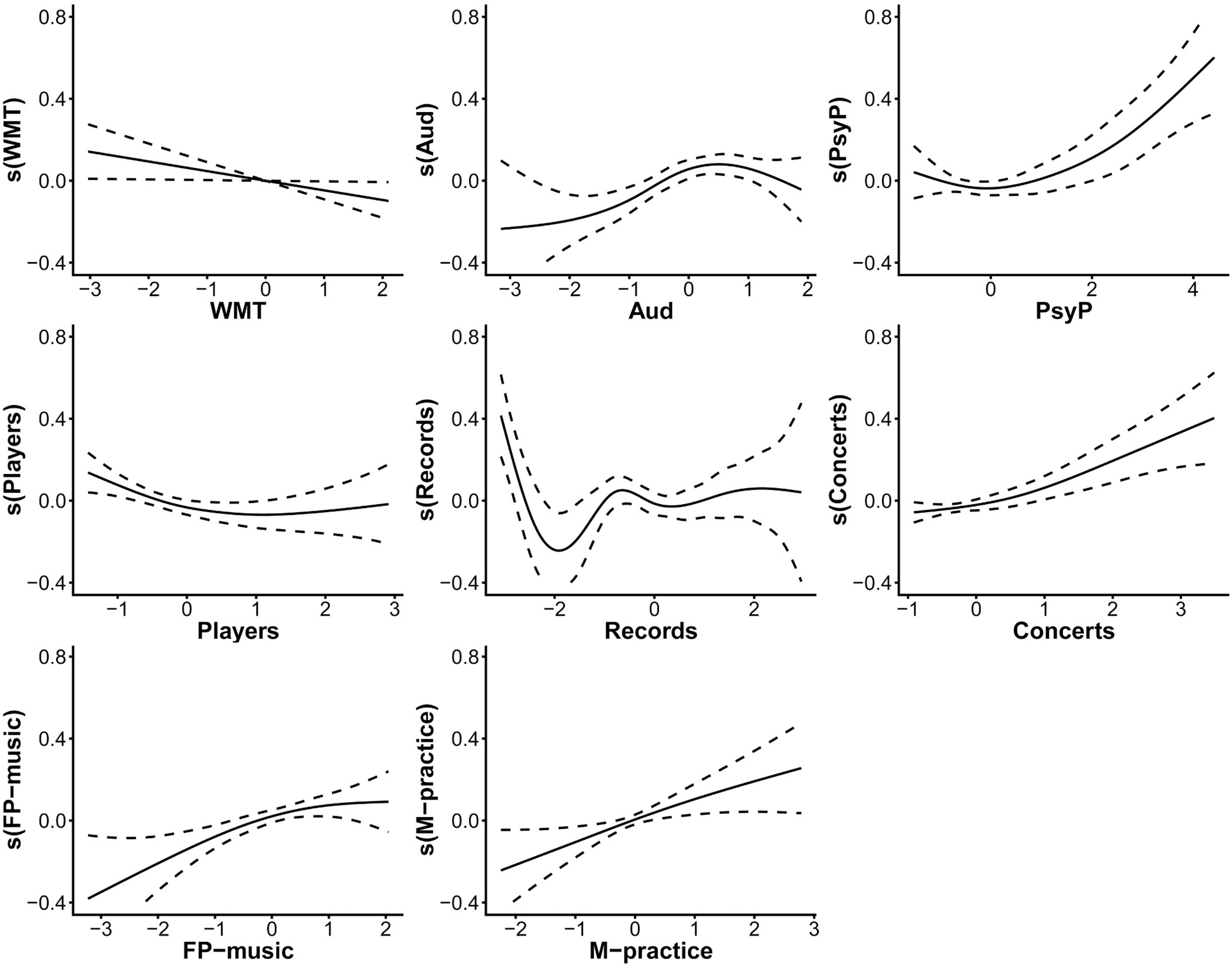

Fig. 6. GAM of professional musical achievements – visualization of the significant smooth functions. The partial effect is represented as a smooth function of the independent variable on the y-axis. WMT = Wiener Matrizen Test (intelligence), Aud = auditory ability, PsyP = psychosis proneness, Players = number of players of music instruments in childhood environment, Records = number of music recordings in childhood home, Concerts = frequency of attending concerts as a child. FP-music = flow proneness during musical activities, M-practice = total hours of music practice.

than 1.1 M individuals and showed that bipolar disorder was more common in creative professions, and that such professions also had a higher prevalence of individuals with close relatives of patients with schizophrenia, bipolar disorder, anorexia nervosa, and autism. Artistic and scientific domains differed with regard to diagnoses; artists were significantly above baseline on bipolar disorder, unipolar depression, and anxiety disorders, and below baseline on drug abuse, while scientists were not above baseline on any diagnosis but significantly below baseline on nine out of eleven diagnoses except autism and anorexia nervosa. As impressive as these studies are, associations between occupational choice and genetic risk for psychiatric disorders do not by themselves provide evidence that mental illness or psychosis proneness are directly related to creative cognition. Psychiatric symptoms could make holding an "ordinary" job challenging, and individuals who experience such symptoms might therefore tend to seek out occupations with more freedom to adapt work to specific abilities, needs, and limitations, and where the value of products are more based on subjective opinions or consensus than objective measures. Many artistic professions fit this description and could provide a welcoming refuge. If this latter scenario turned out to be the main explanation, there would be less of a direct link between psychosis proneness and creative output. That is, psychosis proneness would help classify between individuals working in creative and non-creative occupations, but it would not predict achievement among professionals. Here we importantly present the evidence required to reject this latter hypothesis (as the sole explanation) by showing an association between the proneness for positive symptoms of psychosis and the number of real-life creative achievements within a group of professional musicians, while simultaneously controlling for a wide range of other personal characteristics. The direction of causation from psychosis proneness to creative achievement is suggested by the fact that shared underlying environmental and genetic factors influence both musicianship and mental health (Power et al., 2015; Wesseldijk, Ullén, et al., 2019). Also, the reverse causality arguably has less face validity, particularly given the exponential effect, which would mean that a person's proneness for positive symptoms of psychosis was accelerated for every musical product and/or taught music student. In addition to the direct influence of psychosis proneness on perception and ideas, person-environment fit theories present another interesting reason for why there might be an association with achievement. Since people who pursue similar careers tend to be similar on various domain relevant characteristics, they may also through processes of socialization develop a culture that reinforces central traits

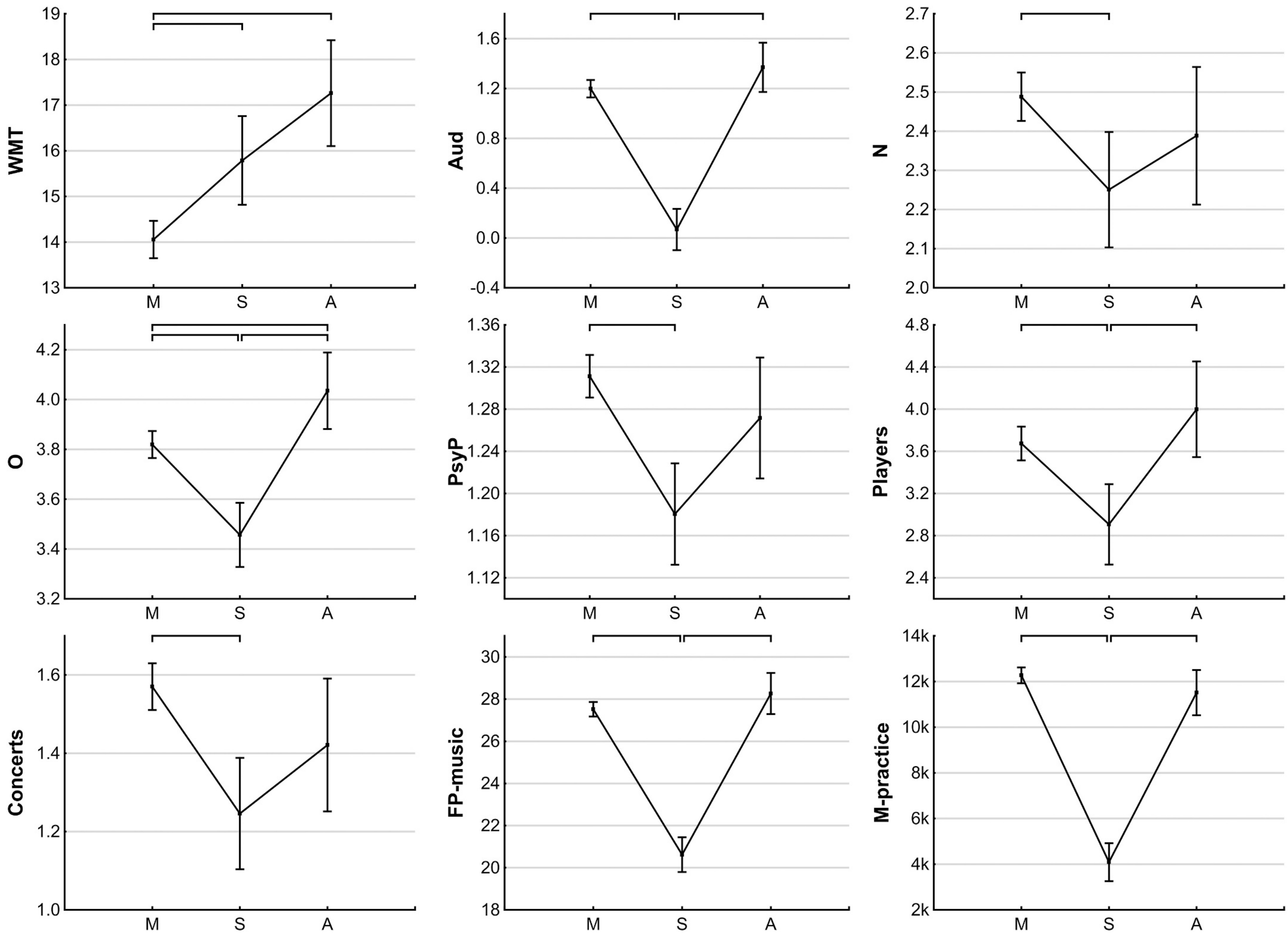

Fig. 7. Least squares means of traits with significant differences between professional musicians, scientists, and/or ambiprofessionals. x-axis: M = musicians, S = scientists, A = ambiprofessionals; y-axis: WMT = Wiener Matrizen Test (intelligence), Aud = auditory ability, N = neuroticism, O = openness, PsyP = psychosis proneness, Players = number of players of music instruments in childhood environment, Concerts = frequency of attending concerts as a child. FP-music = flow proneness during musical activities, M-practice = total hours of music practice.

and influences group membership (Holland, 1997). Many interest groups and occupations, particularly those that depend on a high degree of specialization, are associated with certain stereotypes. Scientists for instance, can be thought of as competent but at the same time somewhat cold (Fiske & Dupree, 2014). Similarly, one stereotype of artists is a higher level of eccentric behaviors and mental illness (Kyaga et al., 2013), which in music has been reinforced by equally famous and infamous genius-level musicians like the drummer Keith Moon and bassist Jaco Pastorius. Given a liberal environment and salient role models, there might have been a self-promoting influx of individuals with proneness for positive symptoms of psychosis who have gradually shaped a cultural domain that not only accepts but also to some extent values and encourages creative products inspired by aberrant cognitive experiences.

Moving on, concerts in childhood had the second largest effect on achievements, very close in magnitude to that of psychosis proneness. Early live music experiences can, as already mentioned, induce strong emotional reactions and transcendental experiences that may open “a new world” and inspire individuals to become musicians themselves (Gabrielsson, 2011). The present findings suggest that similar experiences can even have so profound and long lasting effects that they also influence adult professional musical achievement. This begs for more quantitative research on the effect of early live musical experiences.

Auditory ability also had a significant effect, but the smooth function illustrated an exponential rise that was eventually attenuated. One explanation could be that there is a threshold beyond which auditory ability is practically good enough for reaching any level of achievement. Here, that threshold appeared to be just above the average of auditory ability among professional musicians. This finding again highlights the usefulness of GAMs in revealing complexity that cannot be found with linear models. We must of course concede that there are several potentially important additional relevant (music) specific abilities/skills that were not measured here, such as mimicry, manual dexterity, long-term memory for melodies and fingering, sight-reading, musical improvisation, artistic/emotional expressiveness, etc. (McPherson, 2016). In the present study, the reason for including auditory ability was primarily that it would enable us to contrast the predictive value of a domain specific ability with more general ability in relation to musical achievement. To that end, we chose to focus on a traditional measure of auditory ability with good psychometric properties (Ullén et al., 2014) and previously demonstrated discriminative and external validity (Butković et al., 2015; Mosing, Madison, et al., 2014). The subtests of the SMDT (pitch, rhythm, and melodic memory/discrimination) all correlate (around $r = 0.3$–0.4) and we assume that the composite SMDT score mostly indicates the broad ability of auditory processing (*Ga*) in the CHC framework (McGrew, 2009). The incremental value of introducing additional facets of musical ability is an open and interesting question for future studies. Based on the conclusions drawn here, one hypothesis would be that the more specific the behaviors studied (e.g. composing vs. pedagogy) the larger the unique predictive validity of relevant narrow abilities.

In addition to the above variables, which were also significant in all the logistic GAMs, there were significant effects of general cognitive ability, the remaining childhood variables, music flow proneness, and music practice. Higher WMT scores were found to have a negative effect on achievement, which is a highly surprising outcome. Given that the Pearson correlation between the two was also negative (Table S3), it cannot be attributed to the multivariate context. Instead, we suggest that similarly to the smooth function for auditory ability, the function for WMT indicates that a general ability threshold was reached by most, if not all, professional musicians and that the remaining weak negative relation could be an artefact of a confounding effect of age (positive loading on achievement and negative on WMT) that was not properly accounted for in this model. Viewed in combination, the smooth functions for the ability measures somewhat questions the generality of the conclusion that greater ability leads to greater achievement (Lubinski & Benbow, 2021), particularly considering that this study had ability measures with seemingly adequate ceilings (1.2% of the professional musicians achieved a perfect WMT score; the composite measure for auditory ability was normally distributed), an outcome measure with no ceiling, a fairly large sample size, and a sample of adult professionals who would have had the chance to reach requisite expertise for achievements.

Music recordings and music players in childhood both had smooth functions that started with a decline. This indicates that there was a subgroup of musicians that grew up with few players or musical recordings in the home, but nonetheless went on to accumulate a large number of musical achievements as adults. Perhaps those who had little support at home but anyway sought out a career in music were particularly talented or motivated, but about this we can only speculate. The Records variable showed a lot of variability in the smooth functions across all analyses and it might be that this item/scale needs to be refined, and a general suggestion would be to use a larger pool of items for measuring childhood exposure to music in future studies.

Music flow proneness, i.e. the tendency to have frequent flow experiences during music activities, has previously been shown to predict music practice and the level of engagement in music (Butković et al., 2015). It might seem unsurprising to find that professional musicians more frequently than amateur musicians experience clear goals, complete concentration, total control, and extreme satisfaction during music activities but here, we go one step further and for the first time show that music flow proneness also predicts musical creative productivity. There are at least three hypotheses to why this would be the case (de Manzano, 2020). First, domain specific flow proneness is important for (intrinsic) motivation, and may thus promote continued engagement, practice, and expertise; second, the experience of flow might be a reward signal to indicate optimal psychophysiological task adaptation and could therefore be an epiphenomenon to other factors that jointly promote efficient and successful skill acquisition; third, numerous first person accounts suggest that flow experiences *per se* may facilitate creative cognition (Csíkszentmihályi, 1997). The present finding greatly motivates further research on flow and creative performance.

Music practice was also related to the number of accumulated achievements, which may seem trivial, but two points can be made, given that so many other variables were included in the multivariate analysis. First, practice has been described as the main or even the only factor that determines performance outcomes at the professional level (Ericsson, Krampe, & Tesch-Römer, 1993), but it is clear from the present findings that practice is not the only, or even the strongest predictor of musical achievements. This fits well with meta-analyses on expertise that promote multifactorial models to better account for real life data (Hambrick et al., 2014; Macnamara, Hambrick, & Oswald, 2014; Ullén et al., 2016). Second, practice *does* provide a unique contribution to creative achievement. Mastery of an instrument is of course a predominant feature of most musical educations and technical ability is certainly one aspect of what attracts people to listen to music and watch musical performances in the first place. The bottom line might be that hard relentless work pays off in the end, and there are few shortcuts to success.

Contrary to the expectations, the effect of openness was not significant. This is in itself interesting, as openness is often found to be the main predictor of creative achievement. Two reasons for the lack of an effect on professional achievements could be, first that the measure includes items on artistic and musical sophistication; as discussed previously (see Introduction), responses on these items will trivially differ between musicians and non-musicians and thus have a large effect in an achievement/attainment measure such as the CAQ, but be less useful for predicting achievement within a group of professionals. Second, previous research did not include many of the other relevant and correlated variables included in the present analysis. Since openness was here found to correlate with all but three variables, it seems plausible that some of the shared variance was attributed to other predictors, such as auditory ability and music practice. There are other conceivable options but they appear less plausible. Openness could have reached a threshold in the professional musicians, but in the partial smooth function for openness (Fig. S1) there is no indication that the effect would have reached a plateau. Further, openness was high in the professional musicians but there was no sign of a huge ceiling effect since the mean and standard deviation was only 4 ± 0.57 (out of a maximum of 5).

In contrast to the logistic GAMs for musicianship, adding interactions to the GAM for professional achievements made a difference with both interactions being significant, i.e. between psychosis proneness and openness, and between music flow proneness and auditory ability. A central part of the trait openness involves ideas and fantasy, being ingenious, philosophical, and original, having a vivid imagination, coming up with new ideas and enjoying playing around with them. Positive symptoms of psychosis involve perceptual abnormalities, bizarre experiences, and delusional ideations. It would have been curious if these two traits had not interacted in some way. While openness describes the tendency for, and perhaps intrinsic reward associated with creative cognition, positive symptoms of psychosis may affect the vividness, structure, and experience of musical stimuli, real or imagined, as well as the encoding, retrieval, and filtering of stored musical features and concepts. In combination, these traits might enable a person to generate creative output that others find particularly novel and interesting, which in turn could have a positive influence on productivity and popular demand. Alternatively, creative ideation and productivity might be increased by hypomanic tendencies (Baas, Nijstad, Koen, Boot, & De Dreu, 2020). Further, it can be noted that the interaction between openness and psychosis proneness appears to be driven by a smaller group of participants. This could indicate that it is relatively rare to have high levels of both these traits and be able to make use of it, which might contribute to the right skewed distribution of achievement. It does however also mean that these findings should preferably be replicated before drawing too strong conclusions. The interaction between music flow proneness and auditory ability increased steadily throughout the range of both measures, and is perhaps more straightforward to interpret. Having a good musical ear and finding musical activities intrinsically rewarding provides a synergy that increases productivity. It is interesting to note however, that this interaction between ability and interest was based on highly domain specific traits, which aligns well with person-environment fit theories. Together with exponential effects of domain relevant traits, as here in the case of psychosis proneness, interactions such as those demonstrated here could help explain why the distribution of achievements is skewed to the right, perhaps along the lines proposed for the association between auditory ability and level of musicianship above. There are of course other conceivable person-environment interactions besides those mediated by positive reinforcement. For instance, a studio musician who gets an opportunity to perform and proves competent, reliable, and easy to work with, is likely to be called back repeatedly since there is no point for the studio to look for someone else. This is a type of winner-takes-all situation, and such are arguably common in the music industry. This will boost the number of achievements of musicians who happen to be in the right place at the right time (with the right stuff). van de Rijt et al. (2014) also elegantly illustrated the value of social feedback in reward systems. The authors provided initial advantages in the form of money, quality ratings, awards etc. to arbitrarily selected participants in different domains, which increased the probability for others to make additional investments. That is, success was amplified through social networks. It could be argued that the popular music industry has evolved to utilize precisely these type of social processes when creating hits, stars, and large audiences, based on "discovered" musical talent. Notably, such success-breeds-success phenomena would boost the number of achievements beyond what could be expected purely based on the personal characteristics of the artist, and might therefore attenuate the relation between personal traits and number of achievements at higher levels. The smooth functions illustrated here could be taken to suggest that this was the case for both general and auditory ability, as well as for music flow proneness. The significant effects that showed no signs of being attenuated at higher levels of professional achievement were psychosis proneness (which instead accelerated), childhood concert going, and music practice.

Lastly, there was in addition to the variables of interest a significant effect of sex in favor of males. Since the model accounted for a wide range of personality traits and abilities as well as musical genre and occupation, the underlying reasons for the effect would have to be found elsewhere (see Baer and Kaufman (2008) for a review of gender differences in creativity). We obviously lack the data to draw any conclusions here, but invite more research on the topic.

5.3. Personal characteristics of ambiprofessionals

The third hypothesis, which was deduced from the previous two, stated that individuals who attain a professional level in two domains must possess all the most domain relevant traits of both domains. This hypothesis could also be confirmed in the corresponding analysis. The ambiprofessionals, i.e. those who had reached a professional level in both music and science, had a general ability similar to the scientists and an auditory ability similar to the musicians. Interestingly, and in line with research already mentioned (Kyaga et al., 2013), musicians had higher psychosis proneness than scientists. One explanation for this relates to that creative cognition may involve different strategies (Pinho, Ullén, Castelo-Branco, Fransson, & de Manzano, 2016). On average, artistic creativity may depend more on spontaneous associations and emotional involvement than scientific creativity (Eysenck, 1995; Feist, 1999), which instead tends to involve more systematic and effortful cognitive processes (Simonton, 1999). Thus, as discussed previously, an artist might be able to leverage on positive symptoms of psychosis in the creative process, while for a scientist such symptoms might interfere with the rational planning, organization, and execution of systematic long-term efforts. For example, an artistic rendition of a psychosis-like experience might spur curiosity and be considered an original and useful contribution, while such experiences do not usually make viable premises for scientific endeavors, nor do they help meet the standards by which scientific products are typically valued. All the more interesting then to find that ambiprofessionals had an average level of psychosis proneness that fell in between the average levels of musicians and scientists. It might be that this intermediate level is optimal (or necessary) for navigating both domains. Further, the ambiprofessionals had higher openness than the "uniprofessionals". Perhaps the increased intellectual curiosity, ideational prowess, and reluctance of routine work invites individuals with high openness to engage (and succeed) in multiple domains—provided that they possess the traits that are relevant in these domains. One caveat here is that we do not know whether the participants were engaged at a professional level in both domains simultaneously, or whether they had changed careers at some point. However, this does not affect the overall conclusion.

5.4. Interpretations of partial effects in the presence of genetic pleiotropy

When it comes to the reported differences in outcomes between the univariate and multivariate analyses with regard to the significance of certain variables such as general ability, it is worth noting that the three associations between intelligence and music practice, intelligence and auditory ability, and auditory ability and music practice have all been found to be driven predominantly by genetic factors (Mosing et al., 2019; Mosing, Madison, et al., 2014; Mosing, Pedersen, Madison, & Ullén, 2013, 2014). It is therefore reasonable to expect that the phenotypic correlations between all three traits are largely driven by the same genetic factors (genetic pleiotropy). This is could be true also for openness, music flow, and music practice (Butković et al., 2015), for which the genetic overlap across the three associations was found to range between 61–76%. Further, having a musically enriched childhood environment has been found to amplify individual differences in adult music achievements, an effect which appeared to be driven largely by an increase in the importance of genetic factors (Wesseldijk, Mosing, et al., 2019). Thus, genetic pleiotropy adds an important perspective when reviewing results from multivariate models of psychological traits and associated outcomes. It will be the main source of an inherent multicollinearity that makes it difficult and to some extent nonsensical to figure out which of several intrinsically related traits is more important. What we can safely conclude here, is that the domain specific measures were overall more useful than the broad psychological measures in predicting achievement.

5.5. On the generalization of non-linear effects

Despite GAM being a well-established approach that tends to give balanced and robust outcomes, the data can be such that the regularization process is compromised. This can for instance be a problem at lower sample sizes, or if sampling is uneven and groups of data points with relatively high leverage 'pull' on the spline. One sign of overfitting is predictors with no real effect on the response, despite having fairly high estimated effective degrees of freedom. In our analyses however, the results mostly show highly significant effects, and in the case of non-linearities, quite smooth functions penalized down to 2–3 effective degrees of freedom. In the logistic GAMs, most significant effects were in fact penalized down to linear functions ($edf = 1$). As noted, the effect of music recordings in childhood in the GAM of professional musical achievements was odd, but probably less related to overfitting and more related to an unsatisfactory design of that measure. One additional effect that stood out was the effect of age in the GAMs where professional musicians were involved, which could be attributed to a small number of professional musicians with high age and high achievement. Since age was an effect of no interest, we would argue that the non-linear fitting worked in our favor, because we actually wanted to adjust for this effect, and were not interested in how it would generalize to another sample.

6. Conclusion

This study confirms that in music, and potentially in other occupational fields where performance relies heavily on specific skills and competences, it is domain relevant experiences and characteristics more than broad traits that predict level of engagement and achievement. Such measures identified professionals from amateurs and non-practitioners, and were also, importantly, key to predicting differences in achievement between professionals. This conclusion aligns well with person-environment fit theories (Dawis & Lofquist, 1984; Holland, 1997). In practice, most music schools already apply this principle in their recruitment processes. Children who apply, usually have to perform a series of practical tests that specifically address their musical abilities, such as keeping the beat and reproducing rhythms, limb and finger coordination, harmonizing their voice with others, remembering melodies, playing with emotional expression etc. In domains where the cognitive demands are more varied or load more on executive functions, it is fair to assume that general ability comes out as more important, as was seen in the contrast between scientists and musicians. Thus, studying broad traits across creative domains or occupations, is only going to give a limited view on what factors facilitate professional achievement. Moreover, student samples or samples with a low prevalence of actual experts are not going to give very accurate predictions about high levels of creative achievement, which is generally the goal, due to the obvious restriction of range in expertise and associated inability to observe potential non-linear effects similar to those shown here (which may develop over longer time periods). In conclusion, we confirm the general hypothesis, that a person selects and is selected to an occupation in music based on characteristics relevant for task performance and central for the culture, atmosphere, and consensus on how to value individual performances in the domain; and furthermore, that those who display the best fit also tend to flourish the most.

Funding

This research was supported by the Bank of Sweden Tercentenary Foundation (M11-0451:1) and the Sven and Dagmar Salén Foundation.

Declaration of Competing Interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.intell.2021.101584.

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