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Heritability of Creative Achievement

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Although creative achievement is a subject of much attention to lay people, the origin of individual differences in creative accomplishments remain poorly understood. This study examined genetic and environmental influences on creative achievement in an adult sample of 338 twins (mean age = 26.3 years; *SD* = 6.6 years). Twins completed the Creative Achievement Questionnaire (CAQ) that assesses observable creative accomplishments in various domains. The CAQ includes Artistic Creative Achievement (ACA), Scientific Creative Achievement (SCA), and the Total Creative Achievement (TCA) scales. Across all 3 scales, monozygotic twin correlations were consistently and substantially higher than dizygotic twin correlations, suggesting the importance of genetic influences on creative achievements. Heritability estimates for the 3 scales ranged from 43% to 67%, with the remaining variance being attributable to nonshared environmental influences plus measurement error. The effects of shared environmental factors were negligible. These results were in contrast with those of early twin studies of creativity, which yielded a significant amount of shared family environmental influences. Discrepancies in findings between this study and prior investigations may be due in part to the differences in ages of twins and measures.

Creative achievements improve the quality of human life and provide inspiration, insights, and comfort. Despite its importance, empirical studies on creative achievement are scarce, and the origin of individual difference in creative achievement is much less understood, as compared to other psychological constructs. Early twin studies of creativity showed modest genetic influences and substantial shared environmental effects on the development of creativity. This pattern of findings was evident especially when creativity was measured with divergent thinking performance that taps cognitive facets of creativity. For example, Reznikoff, Domino, Bridges, and Honeyman (1973) gave divergent thinking tests to adolescent twins aged from 13 to 19 years and detected little evidence for heritability. A review of 10 twin studies of creativity published before 1971 yielded average twin correlations of .61 for monozygotic (MZ) twins and .50 for dizygotic (DZ) twins, indicating about 20% of genetic influence and about 40% of shared environmental influence, with the remaining variance being attributable to nonshared environmental variance including measurement error (Nichols, 1978). Canter (1973) suggested that genetic factors in creativity might be due to the overlap between creativity and general cognitive ability tests because when general cognitive ability was statistically controlled, MZ and DZ twin correlations for tests of creativity became similar, underscoring the importance of shared family environmental factors. Substantial shared environmental influences on creativity were also found from a Russian twin study: In a sample of 60 MZ and 63 DZ pairs of adolescent twins, Grigorenko, LaBude, and Carter (1992) reported correlations of .86 for MZ and .64 for DZ pairs on the Russian version of the verbal Torrance Test of Creative

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Thinking (TTCT), yielding estimates of 44% genetic effects, 42% shared environmental effects and 14% nonshared environmental effects plus measurement error. Similar results were discovered in the study of musical abilities: Coon and Carey (1989) showed the effects of shared family environmental influences to be consistently larger than heritability estimates in measures of musical interests and performance, and receiving honors in music from analyses of data collected from high school twins who participated in the National Merit Scholarship study (Loehlin & Nichols, 1976).

In contrast to divergent thinking tests, twin studies that employed measures of *creative personality* yielded roughly half genetic and half unique environmental influences with near zero shared environmental factors (Plomin, DeFries, McClearn, & McGuffin, 2008). For example, Waller, Bouchard, Lykken, Tellegen, and Blacker (1993) administered the Creative Personality Scale (CPS) to a small sample of adult twin pairs who were reared apart and united in adulthood. In the Waller et al.'s study, MZ twin correlation was .54, whereas DZ twin correlation was near zero ($r = -.06$), suggesting substantial heritability and negligible shared environmental influences on the CPS. The authors concluded from these results that creativity might be an emergenic trait determined by complex, higher-order interactions of multiple alleles at different loci so that only relatives who share complete genetic make-up (i.e., MZ twins) can show much resemblance.

Using adult twins (ages 21–74 years) in Germany, Penke (2003) investigated genetic and environmental influences on self- and peer- and video-rating of creativity and found substantial genetic influences (.29 ~ .58) and near zero shared environmental influences. Penke also extracted a general factor of creativity from self-, peer- and video-rating of creativity. The variance of the general factor was predominantly explained by genetic variance (.61), with the remaining variance (.39) being attributable to nonshared environmental influence including measurement error.

Another reason that large shared-environmental factors and modest genetic influences were found in early twin studies of creativity may be that these studies typically investigated children and adolescent twins. It has been well documented that heritability for most psychological traits, especially cognitive abilities tend to increase from childhood to adulthood, and shared environmental influences decrease (Plomin et al., 2008). Indeed, studies based on adult twins provided evidence for substantial genetic influence. In a small sample of young adult twins, Barron and Parisi (1976) found that MZ twins were more similar than DZ twins in emotional and esthetic expressiveness, indicating the importance of genetic factors.

Recently, using a large, population-based sample of Dutch adolescent and young adult twins (ages 12–24 years), Vinkhuyzen, van der Sluis, Posthuma, and Boomsma (2009) found substantial heritabilities for Talent Inventory (McGue, Hirsch, & Lykken, 1993), a self-rating measure of aptitudes and exceptional talents in music, arts, writing, language, chess, mathematics, sports, memory, and knowledge. The authors reported heritability estimates to be between .32 and .71 for the nine domains of aptitudes and between .50 and .92 for exceptional talents in these domains. Shared environmental influences were not significant in any domain of aptitudes or exceptional talents.

The main goal of our study was to determine genetic and environmental influences on creative achievement in a sample of Italian adult twins. The study of creativity has suffered from disagreements among researchers in the definition of creativity, which generated much confusion and methodological problems concerning reliability and validity of creativity measures (Piffer, 2012). In proposing a framework of the study of creativity, Runco (2007) broadly organized creativity into two categories: creative performance versus creative potential. According to Runco's scheme, our study fits in the field of creative performance. Defining creativity as creative product that is original, functional, and socially useful, this study employed the Creative Achievement Questionnaire (CAQ) developed by Carson, Peterson, and Higgins (2005) that measures the lifetime sum of creative products in different domains generated by an individual.

METHODS

Sample

The sample includes 338 twins, consisting of 79 complete pairs of MZ and 90 complete pairs of same-sex DZ twins who volunteered to participate in this study in response to a solicitation letter. The solicitation letter was mailed to the address of the same-sex twins born between 1980 and 1992 in different regions of Italy. The mailing addresses of the twins were obtained from city councils. Incomplete twin pairs were excluded from this investigation. Zygosity of twins was determined by self-report questions. Twins who were not sure about their zygosity were excluded from data analyses. The mean age of the total sample was 26.3 years, with an *SD* of 6.6 years. Sixty-two percent of the sample was women. As in most volunteer twin samples, this sample has an overrepresentation of women (Lykken, McGue, & Tellegen, 1988).

Measures

The CAQ is a self-report measure of real-life creative achievements and includes questions on creative achievements in 10 domains, i.e., visual arts (painting & sculpture), music, dance, architectural design, creative writing, humour, invention, scientific discovery, theatre and film, and culinary endeavors. As compared to other self-rating instruments of creativity that measure one's belief on his or her creativity, the CAQ has more objectivity as it measures one's observable creative performance concretely. Test–retest and internal consistency reliabilities and convergent and divergent validities have been well established (Carson et al., 2005). Twins filled out the questions of the CAQ via the Internet (Freeonlinesurve.com). Twins were instructed to indicate the extent to which their creative achievements had been recognized in each domain on a score ranging from 0 (e.g., "I have no training or recognized talent in this area") to 7 (e.g., "My work has been cited by other scientists in national publications"). For each domain, the level of accomplishment was very concretely and objectively stated. For selected domains, respondents were also requested to indicate how many times each achievement has been earned (e.g., number of publications) next to the option 7 so that additional weight can be given. However, to avoid an extremely skewed distribution of the scores, regardless of the number of achievements, 7 points was assigned as the maximum score one can obtain for each domain.

The CAQ includes the Total Creative Achievement (TCA) scale, and two scales developed from factor analyses, that is, Artistic Creative Achievement (ACA) and Scientific Creative Achievement (SCA; Carson et al., 2005). A TCA score was created by summing the scores across all 10 domains. The ACA, which assesses creative achievement in arts, included visual arts, music, humour, creative writing, dance, and theatre and film domains of the CAQ. An ACA score was computed by summing the scores across these six domains. The SCA consisted of the scientific discovery, scientific invention, and culinary endeavors domains of the CAQ. An SCA score was generated by summing the scores of these three areas.

STATISTICAL ANALYSIS

To examine genetic and environmental influences on TCA, ACA, and SCA, twin correlations for MZ and DZ twins were calculated and univariate model-fitting analyses were performed. The standard univariate twin model (Figure 1) assumes that the variance in a trait can be decomposed into four components, that is, additive genetic factors that refer to the sum of the average effects of all genes that influence a trait (A), nonadditive genetic factors that represent the effects of intralocus, as well as interlocus, interactions of genes (D), shared environmental factors that include those environmental effects shared by the two members of a twin pair and make twins similar (C), and nonshared environmental factors including measurement error, which includes those environmental factors unique to each member of a twin pair and, therefore, make twins different from each other (E). Because MZ twins share all their genes and DZ twins share, on average, 50% of their segregating genes, a higher MZ than DZ twin correlation would indicate the presence of additive genetic influences. If the DZ twin correlation is greater than one-half the MZ twin correlation, then the importance of shared environmental factors for their similarity is indicated. On the other hand, the presence of nonadditive genetic factors is indicated if the DZ twin correlation is less than half the MZ twin correlation. MZ twin correlation less that 1.0 represents nonshared environmental influences and measurement error. As the estimates of C and D depend on each other, the ACE and the ADE model were both tested and then a decision was made between the two.

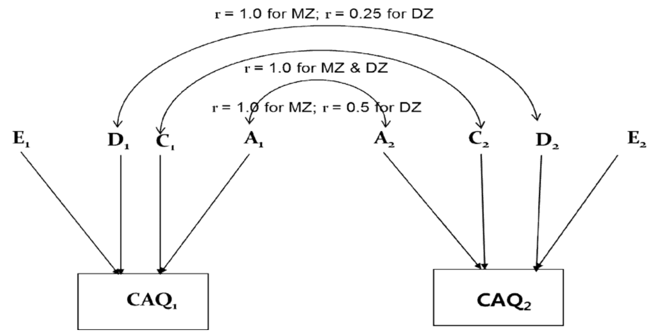

FIGURE 1 Univariate model: additive genetic (A), nonadditive genetic (D), shared environmental (C) and nonshared environmental factors including measurement error (E) on the score of the scales of the Creative Achievement Questionnaire (CAQ) for twin pairs. Subscripts 1 and 2 refer to the first-born and the second-born twins, respectively. MZ = monozygotic twins. DZ = dizygotic twins.

Model-fitting analyses were performed using the raw data option in Mx (Neale, Boker, Xie, & Maes, 2003), which calculated twice the negative log-likelihood ($-2LL$) of the data. Because the difference in $-2LL$ between the full and the nested model is distributed as a chi-square, it allows for a test of the difference in model-fit. A significant change in chi-square suggests that constraining the parameter in the nested model caused a significant decrease in fit of the model, whereas a nonsignificant change indicates that constraining the parameter is acceptable. When alternative models are not nested, Akaike Information Criteria (AIC = −2LL-2df) was used to evaluate superiority among competing models. Generally, models with lower AIC values are considered to represent better and more parsimonious fits to the data than are models with higher AIC values (Akaike, 1987). For a baseline comparison, a saturated model where means and variances were freely estimated for MZ and DZ twin groups was generated and the value of −2LL of the saturated model was compared to that of the full model.

RESULTS

Descriptive Statistics and Twin Correlations

None of the three scales, TCA, ACA, and SCA, was significantly correlated with age ($-.09 < r < .01$) in our sample. Although men showed slightly but consistently higher mean level than did women in all three scales, sex differences in the mean level did not attain statistical significance. However, variances were significantly higher in men than in women in all three scales. Across two zygosity groups, there were no significant mean or variance differences in three scales, fulfilling the assumptions for twin analyses (see Table 1).

TABLE 1
Sample Size, Age, and Sex Composition, and Means, SDs, and Maximum Likelihood Twin Correlations for the Total Creative Achievement (TCA), Artistic Creative Achievement (ACA), and Scientific Creative Achievement (SCA) of the Creative Achievement Questionnaire (CAQ) for Monozygotic (MZ) and Dizygotic (DZ) Twins and the Total Sample

	MZ	*DZ*	*Total*
N (pairs)	79	90	169
M:F (%)	39:61	37:63	38:62
Age in years			
Mean (SD)	27.7 (7.2)	25.0 (5.8)	26.3 (6.6)
Range	16–48	17–46	16–48
TCA			
Mean (SD)	5.3 (7.1)	5.2 (5.5)	5.2 (6.3)
r	.64 (.50–.76)	.32 (.12–.49)	
ACA			
Mean (SD)	3.3 (5.1)	3.2 (3.9)	3.3 (4.5)
r	.70 (.56–.79)	.33 (.14–.50)	
SCA			
Mean (SD)	2.1 (3.5)	1.9 (2.4)	2.0 (3.0)
r	.49 (.31–.64)	.19 (−.02–.38)	

Note. M = male, F = female.

As the distributions of all three scales were highly positively skewed with skewness indices of 2.6 for TCA, 2.8 for ACA, and 4.4 for SCA, prior to twin analyses, logarithmic transformations were performed for the scores of the three scales, which resulted in the skewness indices of .13 for TCA, .45 for ACA and .76 for SCA.

Twin correlation and model-fitting analyses were carried out in a combined sample of male and female twins to maximize the sample size. Even if age and sex effects were small, age and sex were treated as covariates in twin correlation and model-fitting analyses to control their main effects. MZ twin correlations were .64, .70, and .49 for TCA, ACA, and SCA, respectively, and the corresponding DZ twin correlations were .32, .33, and .19 (Table 1). For all three scales, MZ twin correlations were significant and nearly double the DZ twin correlations. These patterns of twin correlations suggested significant genetic and little shared environmental influences on TCA, ACA, and SCA. Nonshared environmental factors appeared to be important especially for SCA as the MZ twin correlation was much less than 1.0. The highest MZ twin correlation ($r = .70$) for ACA indicated substantial genetic influences on creative achievement in the artistic domain.

Univariate Model-Fitting Analyses

Table 2 presents the results of univariate model-fitting analyses. As both ADE and ACE models yielded the

TABLE 2
Goodness-of-Fit Statistics and Parameter Estimates From Univariate Model-Fitting Analysis for Total Creative Achievement (TCA), Artistic Creative Achievement (ACA) and Scientific Creative Achievement (SCA) of the Creative Achievement Questionnaire

		Goodness-of-Fit Statistics						*Parameter Estimates*			
Measure	*Model*	*–2LL*	*AIC*	*Df*	*Δ–2LL*	*Δdf*	*p*	*A*	*C*	*D*	*E*
TCA	ADE	247.4	–416.6	332				.61 (.00, .72)	—	.00 (.00, .69)	.39 (.28, .52)
	ACE	247.4	–416.6	332				.59 (.17, .72)	.02 (.00, .37)	—	.39 (.28, .53)
	AE	**247.4**	**–418.6**	**333**	**0.0**	**1**	**.93**	**.61 (.48, .72)**	—	—	**.39 (.28, .52)**
	CE	254.9	–411.1	333	7.6	1	.00	—	.46 (.34, .57)	—	.54 (.43, .66)
	E	295.8	–372.2	334	48.5	2	.00	—	—	—	1.0[a]
ACA	ADE	210.8	–453.2	332				.59 (.00, .76)	—	.08 (.00, .74)	.33 (.23, .45)
	ACE	210.8	–453.2	332				.67(.32, .77)	.00 (.00, .30)	—	.33 (.23, .45)
	AE	**210.8**	**–455.2**	**333**	**0.0**	**1**	**.99**	**.67 (.55, .77)**	—	—	**.33 (.23, .45)**
	CE	223.3	–442.7	333	12.5	1	.00	—	.49 (.37, .60)	—	.51 (.41, .63)
	E	269.4	–398.6	334	58.5	2	.00	—	—	—	1.0[a]
SCA	ADE	95.2	–568.8	332				.32 (.00, .57)	—	.12 (.00, .57)	.56 (.42, .73)
	ACE	95.2	–568.8	332				.43 (.00, .57)	.00 (.00, .37)	—	.57 (.43, .74)
	AE	**95.2**	**–570.8**	**333**	**0.0**	**1**	**.99**	**.43 (.27, .57)**	—	—	**.57 (.43, .73)**
	CE	98.7	–567.3	333	3.4	1	.06	—	.33 (.19, .46)	—	.67 (.54, .81)
	E	118.2	–549.8	334	23.0	2	.00	—	—	—	1.0[a]

Note. [a]95%CI incalculable. — = parameter constrained to be zero. A = additive genetic influences. C = shared environmental influences. D = nonadditive genetic influences. E = nonshared environmental influences plus measurement error.

same value of −2LL in all three scales, the ACE model was chosen as the full model, given the small sample size in this study and the low power to detect nonadditive genetic factors in the classical twin design (Martin, Eaves, Kearsey, & Davies, 1978). The differences in −2LL between the saturated model and the full model were not significant in any of the scales, indicating that moving from the saturated models to the full ACE models is acceptable. Removing A from the full model (i.e., the CE model) yielded a significant deterioration in model-fit for TCA and ACA, but only a marginally significant deterioration in SCA. When C was dropped from the full model (i.e., the AE model), resulting changes in −2LL were not significant in any of the three scales. Dropping both A and C simultaneously from the full model (i.e., the E model) yielded a significantly poor fit in all three scales, indicating that environmental influences alone cannot explain the variance of creative achievement. Among the submodels, the AE model showed the lowest AIC value for all three scales. Taken together, the results of univariate model-fitting analyses suggested that AE was the best-fitting model. The parameter estimates in the best-fitting model confirmed the impression gained from the inspection of twin correlations. In the best-fitting model, genetic influences on TCA, ACA, and SCA were all significant (61%, 67%, & 43%, respectively). Among the three scales, ACA showed the largest amount of genetic influences, whereas SCA yielded the smallest. For all three creative achievement scales, the nongenetic variance was explained predominantly by nonshared environmental influences.

DISCUSSION

Creativity is often defined in terms of products, that is, expressed outputs of creative potential. As compared to creative potential, creative products such as paintings, publications, and compositions can be easily quantified, and judgments about these creative accomplishments can be more reliable. Using the CAQ that captures observable and high-level of accomplishments in diverse domains, this study, for the first time, investigated genetic and environmental influences on creative achievements in a sample of adult twins. Substantial heritability estimates were found for artistic, scientific, and total creativity, ranging from 43% to 67%. As with other psychological traits in the twin study literature, this study revealed that environmental factors important for creative achievement is predominantly a nonshared, rather than a shared, kind (Plomin et al., 2008). Nonshared environmental factors comprise measurement error and all environmental influences not shared by two members of a twin pair including experiences inside the family. The effects of birth order could be one example as it has been shown that the family constellation dimensions of birth order are related to scientific eminence (Feist, 1993). Another example could be parents' unfulfilled wishes that have been shown to be related to exceptional achievements among creative people (Rothenberg & Wyshak, 2004). If parents' unfulfilled creative wishes are perceived and adopted differently by children in the same family, then these effects would show up as the estimate of nonshared environmental factors in the twin model used in this study.

Twin studies assume that the degree of similarity in rearing environment is approximately equal for MZ and DZ twins (the equal environment assumption) and that there is no genotype-environment (GE) correlation or interaction (Plomin et al., 2008). Violation of these assumptions can lead to biased estimates of heritabilities and environmental influences. Using a variety of methods, the equal environment assumption has been tested extensively. The general conclusion from these test results is that, although MZ twins tend to be treated somewhat more similarly than do DZ twins, differential environmental experiences make little influences on the estimates of genetic and environmental factors in normal behavioral traits and psychiatric illnesses, supporting the validity of the equal environment assumption (Kendler & Gardner, 1998; Kendler, Neale, Kessler, Heath, & Eaves, 1994; Loehlin & Nichols, 1976; Lytton, Martin, & Eaves, 1977).

GE correlation refers to the extent to which individuals are exposed to environments as a function of their genetic propensities. For example, active GE correlation can occur when individuals inherited artistic creativity actively select and create environment conducive to the development of artistic creative achievement. These effects should be examined in future research using various twin study designs incorporating environmental variables. GE interaction occurs when the effect of environmental factors depends upon genotype and vice versa. It is possible that the magnitudes of genetic variances for ACA, SCA, and TCA vary across different environments. However, the sample size in this study is small to test the effects of GE interaction. Future research should increase sample size and examine whether and how the estimates of genetic factors vary across different environments.

The findings in this investigation were generally in line with the results from the Vinkhuyzen et al. study (2009), but contrasted with those of early twin studies of creativity based on children and young adolescents that demonstrated substantial shared environmental factors along with little genetic influence. It may be that the Vinkhuyzen et al. study (2009) and our investigation produced similar results because both samples were based on adults. Innate talent for creative achievements may become more important during adulthood, whereas shared environmental factors such as parental socioeconomic status, parenting style, the school environment, and training experiences shared by siblings may exert influences on accomplishments largely during childhood and early adolescence, and decrease in importance with increasing age. It would be of interest in future research to conduct cross-sectional, as well as longitudinal, twin research on creative achievement to examine whether and how genetic and environmental influences on creative achievement change with increasing age.

One should note that the talent inventory employed in the Vinkhuyzen et al. study (2009) was close to the CAQ. In the talent inventory, nine creative domains are very specifically presented to respondents, and for each specific creative domain, respondents are requested to classify their competence as compared to the general population on a scale including four categories ranging from *less competent than most people* to *being exceptionally skilled*. Thus, similarities in findings from both twin studies may be due, in part, to similarity in measures, as well. Prior twin studies of creativity that yielded large shared environmental influences typically employed divergent thinking performance. Divergent thinking is known to assess creative potential, rather than creative performance although the scores on divergent thinking tests were shown to be significantly correlated with the CAQ (Carson et al., 2005; Piffer, 2011). More twin studies are needed in the future to clarify whether and how estimates of genetic and environmental influences vary across measures of creative potential vs. creative performance.

There is increasing consensus among creativity researchers that creative achievement relies on multiple components, including a high level of disciplined motivation, the personality disposition of openness to new experience, intellectual fluency, flexible cognitive styles, and knowledge (Sternberg, 2006). The large amount of genetic influences found in this study may partly reflect genetic factors for these traits as personality, motivation, and cognitive styles were shown to have genetic underpinnings (Plomin et al., 2008). Recent molecular genetic studies suggested that the dopamine D2 receptor gene (TAQ IA) and a serotonergic gene (TPH-A779C) were associated with creativity: TAQ IA was related to verbal creativity, whereas TPH-A779C was associated with figural and numerical creativity (Reuter, Roth, Holve, & Hennig, 2006). Using verbal and figural ideation fluency scores, Runco et al. (2011) replicated these results partially. However, samples in both studies were small and consisted of university students who had above average intelligence. More recently, Keri (2009) found that a polymorphism of the promoter region of the neuregulin 1 gene (SNP8NRG243177/rs6994992) was significantly associated with the scores of the CAQ and the TTCT. Specifically, those with highest scores in CAQ and TTCT were found in people who carried T/T genotype known to be associated with psychotic features as well (Hall et al., 2006).

The magnitudes of genetic and nonshared environmental influences were different between artistic and scientific creative achievements in this study. Although highly creative individuals in the arts and highly creative individuals in the sciences may share more distinctive traits with one another than they share with less creative individuals in their own field (Vernon, 1989), there is evidence that creative artists display different personality traits than creative scientists (Feist, 1998) and that psychopathology is more prevalent among creative artists than among creative scientists (Ludwig, 1998). In addition, neurological studies have shown that creative achievements in various domains are related to different cognitive factors which tap into different brain regions so that lesions to specific brain areas can be detrimental to performance on certain creative tasks but beneficial for others (Abraham, Beudt, Ott, & von Crammon, 2012). Taken together, these results support domain specificity in genetic and environmental influences on creative achievement. Using both quantitative and molecular genetic analyses, future research should clarify genetic and environmental factors common to artistic and scientific creative achievements, as well as those factors unique to each domain to better understand the relationships among multiple domains of creative achievements.

This investigation has a few limitations. First, although twins in our study were recruited from various regions in Italy, the sample was relatively small and comprised volunteers who may not include sufficient numbers of professionals and nonprofessionals in various fields. The results of this study, therefore, need to be replicated with a larger, more representative sample. Second, data analyses in our investigation were based on a combined sample of men and women. The Vinkhuyzen et al. study (2009) found sex differences in the magnitudes of genetic and environmental influences in the music and sports domain. Future study should, therefore, analyze data separately by sex and compare the results across sexes.

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