THE ROLE OF MATERNAL EDUCATION IN REGULATING GENETIC AND ENVIRONMENTAL CONTRIBUTIONS TO THE DEVELOPMENT OF CHILD'S LANGUAGE COMPETENCIES

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Understanding the role of the environment in the dynamics of gene-environment interactions shaping psychological traits of the child is one of the central issues of contemporary psychogenetics. The socioeconomic status of the parents (education in particular) is a critical factor regulating the share of environmental and genetic influences on the child's cognitive abilities. This work is a study of phenotypic associations between the results of the subtests of the Heidelberg Speech Development Test designed to measure children's speech and language competence, by computing genotypic and environmental correlations between its components. Children were divided into groups based on the educational level of their mothers (medium and high); each group was analyzed separately. For our analysis we used the twin method: the group of twins born to mothers with medium-level education included 17 monozygotic and 11 dizygotic twin pairs; the group of children born to highly educated mothers was comprised of 17 monozygotic and 22 dizygotic twin pairs. All children were aged from 7 years to 8 years and 11 months. Family report forms revealed an association between maternal education and individualized approach to the upbringing of each of the twins. It was shown that in families with highly educated mothers, differences in the upbringing strategies improve the development of language and speech competencies of the child, strengthen the relationship between various language competencies, increase the contribution of the genotype to and decrease the role of the general family environment in this relationship.

Keywords: twin method, genetic correlation, education, psychogenetics, socioeconomic status, environmental correlation, language competence

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РОЛЬ ОБРАЗОВАТЕЛЬНОГО СТАТУСА МАТЕРИ В ИЗМЕНЕНИИ ГЕНОТИП-СРЕДОВЫХ СООТНОШЕНИЙ В СТРУКТУРЕ ЯЗЫКОВЫХ ХАРАКТЕРИСТИК

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Изучение роли средовых факторов в изменении генотип-средовых соотношений по психологическим характеристикам является актуальной задачей современной психогенетики. Важнейший фактор изменения генотип-средовых соотношений по когнитивным способностям — социоэкономический, и в частности образовательный, статус родителей. Исследовались причины фенотипических взаимосвязей между субтестами Гейдельбергского теста речевого развития ребенка путем подсчета генотипических и средовых корреляций между одноименными характеристиками. Анализ проводился раздельно в подгруппах детей из семей со средним и высоким образовательным статусом их матерей. Применяли близнецовый метод: в подгруппу близнецов из семей со средним образовательным статусом матерей вошли 17 монозиготных и 11 дизиготных пар; подгруппу детей из семей с высоким образовательным статусом матерей составили 17 монозиготных и 22 дизиготных пары. Возраст детей — 7 лет — 8 лет 11 мес. На основании анкетных данных показано, что образовательный статус связан с субъектной активностью матерей в вопросах индивидуализации воспитания близнецов в паре. В семьях с высоким образовательным статусом матерей эта установка приводит к возрастанию уровня языкового развития детей, росту структурной связанности различных языковых характеристик, увеличению удельного веса общего генотипического фактора и снижению роли общесемейной среды в объяснении природы этой структурной связанности.

Ключевые слова: близнецовый метод, генетическая корреляция, образовательный статус, психогенетика, социоэкономический статус, средовая корреляция, языковая компетенция

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Personal shapes of various psychological characteristics in children develop under a significant influence of the socioeconomic status (SES) of their parents. The components of SES are family income, educational and professional status of parents. Favorable conditions for the development of children in families with high SES mean a number of things: children can receive high-quality food and medical care; families can choose housing that is more environmentally sound; children enjoy a cognition stimulating environment; the parent-child relationship is harmonic and the upbringing attitudes are positive [1]. In our country, using SES as a criterion for group formation in research studies is hindered by somewhat incomplete questionnaire data obtained from the parent, who prefer to give just a general description of their families' financial standing. Grouping research participants by educational status (ES) of parents turns out to be a productive way of studying the contribution of SES to individual psychological traits [2].

Parents' SES is a factor in shaping individual peculiarities of language characteristics. The relationship between parent's SES and child's language skills development manifests at the age of 1.5 years. By the age of 3, mother's SES and education are positively related to the size and diversity of child's active vocabulary, ability to understand the language, average length of utterance in morphemes, variety of word combinations, compound and complex structures used [3–7]. Children of preschool and school age coming from families with high SES have a large vocabulary, use grammatically and syntactically more complex sentences in their speech, progress significantly in developing reading skills, better cope with verbal tasks than their peers from families with low SES [5, 8–11].

Parents with high SES and ES create an environment that fosters children's language skills development. Mothers from such families are verbally responsive, communicate more with their children and encourage them to communicate, keep up topical conversations longer, tend to avoid giving directive instructions and react to the statements made by children more lively. The lexical and grammatical composition of their speech is rich and contains more information about the surrounding objects. The amount of time high-SES mothers allocate to child-parent interaction is as important for child's language skills development as the average characteristics of mother's speech. Intergroup differences in the volume of active vocabulary possessed by infants from families with different SES are almost completely dependent on the quality of verbal environment [5, 12–14]. At the same time, with children aged 1 through 4 the role of SES in the development of individual differences regarding the richness of active vocabulary diminishes when lexical and syntactic complexity of mother's speech is taken into account [6]. Creating a more development-oriented environment in low-SES families produces a beneficial effect on the development of language mastery [15, 16]. Parental education and income affect parent-child interactions and make a relatively independent contribution to the verbal development of a child between 1.5 and 3 years of age [17, 18]. The studies suggest that SES of parents is a correlate of the level of parental activity aimed at improving the environment that promotes development of language skills.

These studies provide an understanding of the role of a family's SES as an environmental factor affecting variability of language skills. However, language competencies can also be affected by genetic factors. Psychogenetics, a cross between psychology and genetics, aims to research the roles played by hereditary and environmental factors (and their interaction) in the formation of individual variations of psychological characteristics. Studies of the nature of interindividual variability of language competencies prove that this variability is influenced by environmental and genetic factors [20].

An important share of psychogenetic research efforts aims to study the role of environmental factors in the changes occurring in genotype-environment interactions. The researchers rely on the bioecological model proposed by Bronfenbrenner and Ceci, which assumes that the wealth of development resources provided by the child's immediate social environment has a lasting effect on the contribution of distal environmental resources (education, culture, economy) to the development of the child and, furthermore, can influence the expression of developmental genetic predisposition [21]. Scarr believes that environmental characteristics can regulate the ratio of contributions made by genetic and environmental factors to the formation of interindividual variability of psychological characteristics [22].

These assumptions imply that during early ontogeny, individual patterns, like those of cognitive characteristics, must be significantly influenced by factors shared by all family members. With age, the contribution of hereditary factors to the variability of cognitive abilities increases, while the contribution of family-related factors decreases. It was found that SES mediates gene-environment interactions in what concerns children's intellectual development characteristics. Thus, differences in general intelligence observed in 2-year old children from low-SES families can be explained by the influence of family environment. The role of hereditary factors in shaping personal traits increases in children from high-SES families, generally standing on a higher intellectual development level [23, 24]. In 7-year-olds from high-SES families, more than half of phenotypic dispersion of the general intelligence comes from hereditary factors. As for children from low-SES families, about 60 % of their individual differences result from the influence exerted by the general family environment [25]. Psychogenetic studies of verbal intelligence yielded similar results, but they dealt with school-age children [26]. As far as verbal intelligence goes, in early and pre-school age family's SES has a faint influence on the balance of the genetic and environmental contributions [27].

Although most studies confirm the mediating effect of SES on the dynamics of gene-environment interactions in what concerns individual peculiarities of cognitive characteristics, a number of studies report no such effect. Tucker-Drob and Bates provide an explanation for the contradictions. They conducted the meta-analysis of 14 studies revolving around the role of SES in mediating genetic and environmental contributions to the interpersonal variability of intelligence and academic progress and found that such mediation applied to American children. Studies conducted in Western Europe and Australia reveal nothing of the kind. The researchers point out that zero or even negative mediation effect is the product of social policies pursued in these countries, where all population strata have a more or less equal access to quality education and health care [28].

As for the role played by the genetic factors and the environment in the development of language mastery, it was found that the family's SES slightly influences the ratio of their contributions while the age of children is pre-school. Along with home environment orderliness, SES determines only 3–5 % of individual traits while some other factors of the shared environment determine 52–58 % of children's verbal abilities [29, 30]. Research of etiology of individual differences in understanding a written text while reading (8-year old children) revealed that these differences were determined by genetic factors to a large extent and, moreover, contribution of these genetic factors increased in parallel with school SES (derivative of the SES of pupils' families) where the research participants studied. However, only 7.5 % of individual differences in understanding a written text have anything to do with the correlation between genetic and environmental factors and SES of a school [31]. Parental ES influences the balance between genetic and environmental contributions affecting children of primary school age and adolescents. Comparison of the gene-environment ratios obtained from the samples of Russian schoolchildren coming from families with high and medium maternal ES shows that individual differences in the degree of Russian language mastery can be explained by the impact of various factors: as a rule, in the first sample (high maternal ES) the contribution of hereditary factors to the interindividual variability of language skills is much higher than in the second sample (medium maternal ES). In turn, in the second sample individual differences in language skills are largely determined by the environment in general [32]. The adolescent sample shows that language understanding is largely influenced by genetic factors in children from families where parents' ES is high. Children coming from families with low ES prove to have their interindividual differences affected by hereditary and general family factors to an equally small degree [33]. Two other studies investigated reading and language skills possessed by adults. Those studies revealed that the higher SES and ES of the families the subjects grew up in, the better are the skills and the more significant is the role of hereditary factors in the formation of the related individual traits. At that, the contribution of the shared environment decreases or remains unchanged [34, 35].

So far, psychogenetic studies offer little information on the role of SES in changing the etiology of the structure of correlations in the set of linguistic characteristics. Previously, we found that close associations between different linguistic characteristics observed in younger schoolchildren should be attributed more to the genetic factors and less to the family environment [36].

The aim of this pilot study was to analyze the interplay between language competencies by studying phenotypic correlations and to assess the dynamics of genetic and environmental contributions to this interplay considering maternal ES. The aim was achieved through counting genotypic and environmental correlations between the characteristics of language development. This pilot study employed the twin method.

METHODS

The Heidelberg speech development test (Ht) was used to assess language skills [37]. Table 1 contains details on test sections, subtests and skills Ht was designed to research. The "raw" subtest scores were translated into standard scores in accordance with the test guide; the age groups were 7 years — 7 years 11 months, 8 years — 8 years 11 months, which allowed eliminating the age difference factor.

Questionnaires filled by mothers allowed assessing upbringing conditions of twins. The questionnaire designed for the study included 11 questions in the "Family Information" section and 52 questions in the "Twins Information" section. The first section offered questions related to age, parents' ES, number of children in the family, household income, professional status of parents, presence of other adults in the family, family leisure activities. Moving to the second section, mothers had to answer questions about the twins, such as related to the first months of their life (birth weight, injuries, long-term illnesses in childhood), early motor and speech development, relationships with peers, adults, parents. A number of questions pertained to the relationship between twins and individualized educational and upbringing strategies parents may have exercised on each twin. With some typical situations from family life described in the question, mothers were asked to choose one of the suggested answers or write down their own answers when the question was open or when choosing an answer from the presented options was difficult. Answers to each question of the survey were presented as dichotomous scales (except when the data could be presented as ordinal scales).

Statistical analysis was conducted using the SPSS 20.0 package. Data on intrapair correlations in twins and heritability coefficients were taken from our previous study and used for calculation of genetic and environmental correlations [32]. ANOVA was applied to assess differences in the levels of studied characteristics. The association between dichotomous characteristics was measured using the φ coefficient. To obtain phenotypic correlations (r) between the Ht subtests, Pearson's interclass correlation coefficients were calculated for two subgroups of study participants, one gathered from the sample of monozygotic (MZ) twins and the other from the sample of dizygotic (DZ) twins. Each subgroup included one randomly selected twin from each MZ or DZ pair. This was possible because almost all the Ht subtests and final scores were practically the same for MZ and DZ twins (Table 2). The

Table 1. Sections, subtests of the Heidelberg test and corresponding skills

Test section	Subtests	Skills
Sentence structure	Understanding grammatical structures (GS)	Sentence
	Memorization and repetition of grammatical structures (SR)	
Morphological structures	Formation of plural nouns (PN)	Morpheme
	Word formation using the same root (SRW)	
	Formation of degrees of comparison of adjectives (DCA)	
Meaning of sentences	Correction of semantically incorrect sentences (CIS)	Phrase
	Constructing sentences (CS)	
Meaning of words	Completing analogies (CA)	Word
	Grouping concepts based on shared features (GC)	
Interactive meaning	Use of different address forms (addressing the same person differently depending on the context of interpersonal communication) (AF)	Utterance / speech act
	Establishing the relationship between verbal and non-verbal emotionally loaded information (VNI)	
	Coding/decoding of intent (CI)	
Generalization stage	Text (story) memorization and retelling (story) (TM)	Text

samples had similar average Ht scores. Correlations were averaged using Z-transforms. Genetic correlations (rg) between the subtests were calculated according to the formulas provided below, separately for MZ and DZ samples; the results were averaged. The formula for genetic correlations:

$$r_{gij} = \frac{1/2\,(r_{Rij} + r_{Rji})}{\sqrt{r_{Rii}\,r_{Rjj}}},$$

r_{Rij}, r_{Rji} — correlation coefficients between i (trait of one member of the twin pair) and j (trait of the other member of the twin pair); r_{Rii}, r_{Rjj} — correlation coefficients for the same traits of twin pair members. Average genetic correlation was calculated according to the formula:

$$r_g = \frac{r_{g(MZ)}/S^2_{r\,g(MZ)} + r_{g(DZ)}/S^2_{r\,g(DZ)}}{\dfrac{1}{S^2_{r\,g(MZ)}} + \dfrac{1}{S^2_{r\,g(DZ)}}},$$

r_g — genetic correlation coefficient; S_{r_g} — error of genetic correlation coefficient [38]. Environmental correlations (r ') were calculated based in phenotypic and genotypic correlations and heritability coefficients of Ht subtests, using the following formula:

$$r' = \frac{r_g - r\sqrt{hH}}{\sqrt{(1-h)(1-H)}},$$

r_g — genetic correlation coefficient; r — phenotypic correlation coefficient; h and H — correlated traits heritability coefficients [39]. Contributions of family and individual environments to the associations between the subtests were analyzed by comparison of intra-individual and intra-pair cross-correlations of Ht subtests (MZ sample) [40].

The total sample included 68 same-sex pairs of twins aged 7 to 8 years 11 months ($\bar{x}$ = 8.00, S =0.65), 35 of them monozygotic, 33 — dizygotic pairs, all studying in several public schools of Moscow. 36 pairs of tins were girls, 32 pairs — boys. The researchers contacted school authorities asking if they had twins that fit the study criteria, then contacted parents of such twins and obtained their permission to test children's language skills and gather information about mothers using questionnaires (filled in at family residences). As of the time of the study, all children were classified as putatively healthy: mothers reported no abnormalities in their physical and mental development. Each twin underwent testing separately, during his or her free time. The children were grouped based on maternal ES using questionnaires filled by mothers. In one family, only grandmother was raising the twins, so the pair was excluded from the analysis. 17 MZ and 11 DZ pairs constituted the medium ES subgroup, i. e. their mothers had incomplete secondary, secondary or vocational education. 17 MZ and 22 DZ pairs constituted the high ES subgroup, i.e their mothers had incomplete or complete higher education.

RESULTS

ANOVA reveals that the results of many Ht subtests are different for the medium ES and high ES split-twin groups. The differences are statistically significant, reproducible and independent of the zygosity status (Table 2). Compared to the twins from the medium ES group, the children from the high ES group scored better on the following subtests: *Imitation of grammatical structures* ($p < 0.05$ in one group), *Word formation* ($p < 0.001$), *Formation of degrees of comparison of adjectives* ($p < 0.05$ in one group), *Correction of semantically incorrect sentences* ($p < 0.05$), *Sentence construction* ($p < 0.05$), *Address forms* ($p < 0.05$), *Story memorization* ($p < 0.005$). The differences affect final scores ($p < 0.005$).

Comparing maternal survey results (medium ES and high ES), we uncovered possible variations in individualized attitudes toward each twin in a pair. Mothers with high ES tended to dress the twins differently (φ = 0.34, $p < 0.01$), they encouraged the twins to do individual chores more often (φ = 0.33; $p < 0.01$) and tended to engage one child in doing housework rather than both (φ = 0.30, $p < 0.05$). Mothers from this group often pointed out that twins were more likely to help around the house independently of each other and not together (φ = 0.25, $p < 0.05$).

We also calculated phenotypic correlations between Ht subtests in the two samples. Each sample included one of the twins from MZ and DZ pairs whose mothers had high ES (n_1 = 39, n_2 = 39). Significant associations between the majority of subtests were discovered, related to grammar, morphology, meanings of sentences and work with a text as a whole. Presumably, these subtests constitute a relatively unified factor that we called "Language competence." Also reproducible, although minor and low, were correlations in subtests *Grouping of concepts*, *Relationship between verbal and non-verbal information and Intention coding*. No statistically significant differences between the correlations were found; correlation pairs were averaged by the Z-transform. Results are shown in Table 3. The correlations varied from $r_{VN \times CI}$ = –0.076 to $r_{GS \times DCA}$ = 0.711. The weighted average correlation coefficient was r = 0.398. On average, 15.84 % of individual differences in any pair of Ht subtests in a sample of twins brought up by mothers with high ES were due to the mutual variability of scores implied by these subtests. Upon exclusion of subtests *Grouping of concepts*, *Relationship between verbal and non-verbal information* and *Coding of intent* from the analysis (coefficients of correlation inter se and with other subtests), the average correlation coefficient varied from $r_{PN \times VN}$ = 0.096 to $r_{GS \times DCA}$ = 0.711. This means that 77.14 % of insignificant correlations belong to subtests excluded from the Language competence factor. The weighted average phenotypic correlation coefficient was r = 0.548.

Genotypic correlations were calculated for almost all subtests, except for *Address forms*, *Relationship between verbal and non-verbal information* and *Coding of intent* (inter se and with other subtests). The correlations ranged from $r_{gGS \times CC}$ = 0.137 to $r_{gSR \times CS}$ = 0.986. The values of the weighted average correlation (r_g = 0.693) and the determination coefficient allowed us to conclude that an average of 48.02 % of differences in the studied pairs of linguistic characteristics can be explained by shared genetic factors. Exclusion of the genetic correlations between Ht subtests and *Grouping of concepts* subtest from the analysis revealed that the lowest correlation was $r_{gPN \times CS}$ = 0.248 and that the weighted average correlation changed insignificantly (r_g = 0.714), which gave an average of 50.98 % of dispersion of scores in some pairs of language competence characteristics, explained by shared genetic factors.

We found 33 environmental correlations varying from $r'_{RS \times SRW}$ = –0.953 to $r'_{DCA \times CS}$ = 0.894. The weighted average correlation was r' = 0.234, and the average variance of individual differences between any selected pair of characteristics was 5.48 %, explaining mutual variability of scores. Exclusion of the *Grouping of concepts* from the analysis brought the weighted average correlation to r' = 0.277 (determination coefficient r'^2 = 0.077).

To get an idea of the interplay of phenotypic, genotypic and environmental correlations between language competencies of twins from the sample with high maternal ES, we analyzed the weighted averages available for cases with three types of correlations. The weighted average coefficients of phenotypic and genotypic correlation were r = 0.468 and r_g = 0.626, respectively, determination coefficients — r^2 = 0.219 and r_g^2 = 0.392, respectively.

Although environment only marginally influences phenotypic associations between various linguistic characteristics, the nature of these environmental factors is yet to be uncovered. These can be general family factors that, in addition to the genetic factor, result in emergence of the observed associations between linguistic characteristics. However, each language skill may be affected individually, and these effects may ultimately actualize the genetic factor shared by different characteristics, which can also foster phenotypic correlations between Ht subtests.

The following method of analysis gives a provisional answer to the question whether the detected contribution of environmental factors to the structure of the associations between the subtests is mainly based on general environmental influences or some individual environmental factors [40]. The method is based on comparing intra-individual and intra-pair subtests cross-correlations only in the sample of MZ twins. Intra-individual correlations are explained by shared genes, shared environment and similarity of individual environmental influences. Intra-pair correlations can be explained by shared genes and shared environment only, since the individual environmental influences exercised on each twin are different. If intra-individual cross-correlations are significantly stronger than intra-pair correlations, phenotypic correlations between different subtests will result from individual environmental influences. Otherwise, phenotypic correlations will be the result of influence of the same factors related to the family environment.

Table 4 shows averaged intra-individual and intra-pair cross-correlations covering two samples of MZ twins (split-twin samples). No significant differences between these types of correlations were found.

Values of phenotypic correlations between Ht subtests calculated for the sample of twins with high maternal ES were higher than those obtained from the sample with medium maternal ES. Two split-twin subsamples that included one of the twins from MZ and DZ pairs (n1 = 28, n2 = 28) showed many insignificant correlations. In many cases, statistically significant correlations in one subsample could not be reproduced in another. However, no significant differences

Table 2. ANOVA results, two subsamples of twins (one twin in the first subsample, the other in the second subsample)

Effect of factors and their interactions	Zygosity		Educational status		Zygosity × educational status	
	F_{emp}	p	F_{emp}	p	F_{emp}	p
GS_1	1.991	0.163	2.264	0.137	0.139	0.710
GS_2	1.914	0.171	3.555	0.064	1.701	0.197
SR_1	0.776	0.382	3.290	0.074	0.036	0.851
SR_2	0.436	0.511	4.750	0.033	0.003	0.954
PN_1	0.004	0.949	1.606	0.208	0.456	0.502
PN_2	0.639	0.427	0.329	0.568	0.625	0.432
SRW_1	0.393	0.533	11.811	0.001	3.173	0.080
SRW_2	0.281	0.598	11.521	0.001	0.342	0.561
DCA_1	1.224	0.273	5.153	0.027	0.627	0.431
DCA_2	1.175	0.282	3.519	0.065	0.052	0.821
CIS_1	0.101	0.751	10.886	0.002	0.181	0.672
CIS_2	0.014	0.907	4.105	0.047	1.054	0.309
CS_1	0.907	0.345	4.707	0.034	0.877	0.353
CS_2	0.221	0.640	5.291	0.025	0.029	0.865
CA_1	6.337	0.014	1.721	0.194	2.484	0.120
CA_2	0.002	0.963	0.000	0.985	0.482	0.490
GC_1	0.941	0.336	2.239	0.140	0.787	0.378
GC_2	0.016	0.900	3.450	0.068	3.041	0.086
AF_1	0.683	0.412	11.634	0.001	0.118	0.733
AF_2	0.300	0.586	5.734	0.012	1.927	0.170
VNI_1	0.459	0.501	2.366	0.129	0.687	0.410
VNI_2	2.047	0.157	0.048	0.828	0.655	0.421
CI_1	0.064	0.801	0.554	0.460	2.739	0.103
CI_2	0.452	0.504	1.297	0.259	1.456	0.232
TM_1	0.150	0.700	14.043	0.000	1.061	0.307
TM_2	0.325	0.571	9.986	0.002	0.427	0.516
Final $score_1$	1.456	0.232	10.074	0.002	0.021	0.884
Final $score_2$	0.986	0.324	11.010	0.002	0.748	0.390

Note. Subscript 1 — subsample 1 consisting of first members of twin pairs; subscript 2 — subsample 2 consisting of second members of twin pairs; F_{emp} — empirical value of the F-test; p - the exact level of statistical significance.

Table 3. Averaged phenotypic, genotypic and environmental correlations, subtests of the Heidelberg test, samples of twins from families with high and medium mothers' ES

Subtests	GS	SR	PN	SRW	DCA	CIS	CS	CA	GC	AF	VNI	CI	TM
GS		0.549****	0.283	0.509****	0.711****	0.571****	0.544****	0.468***	0.311	0.421**	0.328*	0.167	0.663****
		0.896	0.374	0.428	0.757	0.829	0.760	0.911	0.137	–	–	–	0.800
		0.232	0.225	0.818	0.755	0.655	0.453	–	0.396	–	–	–	0.670
SR	0.487**		0.432**	0.333*	0.585****	0.515****	0.573****	0.456***	0.291	0.222	0.113	0.248	0.555****
	0.542		0.616	0.596	0.702	0.986	0.928	0.905	0.976	–	–	–	0.763
	0.601		−0.048	−0.953	0.250	–	0.380	–	−0.672	–	–	–	−0.314
PN	0.323	0.294		0.207	0.387*	0.345*	0.460***	0.501***	0.181	0.096	0.083	0.093	0.353*
	0.718	0.695		0.380	0.433	0.248	0.483	0.604	0.556	–	–	–	0.293
	–	–		−0.236	0.305	0.534	0.496	–	−0.132	–	–	–	0.509
SRW	0.140	0.170	0.342		0.527****	0.594****	0.348*	0.370*	0.364*	0.473***	0.255	0.237	0.413**
	–	–	–		0.925	0.714	0.664	0.849	0.209	–	–	–	0.549
	–	–	–		−0.646	–	0.096	–	0.729	–	–	–	−0.109
DCA	0.369	0.410*	0.427*	0.225		0.557****	0.544****	0.489***	0.309	0.471***	0.288	0.219	0.545****
	0.214	0.347	0.717	–		0.735	0.865	0.909	0.513	–	–	–	0.577
	0.479	0.448	–	–		0.894	0.356	–	0.148	–	–	–	0.473
CIS	0.501**	0.511**	0.295	0.208	0.087		0.533****	0.538****	0.338*	0.290	0.109	0.192	0.558****
	0.881	0.716	0.576	–	0.002		0.907	0.855	0.284	–	–	–	0.620
	–	–	–	–	–		0.583	–	0.397	–	–	–	–
CS	0.396*	0.355	0.508**	0.107	0.346	0.556***		0.358*	0.141	0.245	0.204	0.167	0.395*
	0.655	0.715	0.767	–	0.432	0.511		0.932	0.944	–	–	–	0.365
	–	–	–	–	–	–		–	−0.198	–	–	–	0.557
CA	0.326	0.431*	0.209	0.120	0.243	0.120	0.275		0.425**	0.232	0.221	0.273	0.513****
	0.496	0.402	0.783	–	0.352	0.476	0.974		0.391	–	–	–	0.727
	0.198	0.464	–	–	0.172	–	–		–	–	–	–	–
GC	−0.072	−0.072	−0.170	0.330	−0.291	−0.040	−0.238	−0.032		0.170	−0.003	0.191	0.236
	−0.164	−0.274	−0.550	–	−0.283	−0.165	−0.679	0.021		–	–	–	0.414
	−0.035	−0.027	–	–	−0.303	–	–	−0.055		–	–	–	0.074
AF	0.516***	0.373*	0.533***	0.289	0.386*	0.517***	0.477**	0.191	−0.058		0.127	−0.076	0.292
	0.682	0.710	0.646	–	0.560	0.611	0.478	0.814	−0.136		–	–	–
	–	–	–	–	–	–	–	–	–		–	–	–
VNI	−0.044	−0.077	−0.122	−0.143	0.096	0.015	0.109	0.034	−0.273	−0.040		0.139	0.317*
	–	–	–	–	–	–	–	–	–	–		–	–
	–	–	–	–	–	–	–	–	–	–		–	–
CI	0.346	0.436*	0.400*	0.222	0.348	0.209	0.396*	0.413*	−0.063	0.365	0.466*		0.156
	0.359	0.715	0.782	–	0.435	0.605	0.689	0.450	0.212	0.657	–		–
	0.359	0.373	–	–	0.324	–	–	0.414	−0.130	–	–		–
TM	0.574***	0.240	0.426*	0.211	0.092	0.571***	0.290	0.171	0.002	0.241	−0.122	0.164	
	0.932	0.396	0.604	–	0.297	0.581	0.648	0.226	−0.055	0.811	–	0.509	
	–	–	–	–	–	–	–	–	–	–	–	–	

Note. Top of the table — data on twins from families with high maternal ES, lower part of the table — data on the sample from families with medium maternal ES. First line in each cell — phenotypic correlations, second line - genotypic correlations, third lines — environmental correlations. Dash means correlations could not be calculated. Hereinafter, levels of statistical significance: * — $p < 0.05$; ** — $p < 0.01$; *** — $p < 0.005$; **** — $p < 0.001$.

between the correlations were found, they can be averaged using Z-transform. Table 3 contains the results.

The correlations ranged from $r_{DCA \times CC} = -0.291$ to $r_{GS \times TM} = 0.574$. The weighted average for all correlations was $r = 0.313$. Thus, individual differences in the pairs of subtests considered, which averagely equal 9.80 %, find their explanation in the mutual variability of the relevant scores. With the *Grouping of concepts*, *Relationship between verbal and non-verbal information and Coding of intent* subtests excluded from the analysis - they accounted for 47.37 % of all statistically insignificant correlation coefficients, — the lowest correlation was $r_{DCA \times CS} = 0.087$. Judging by the average weighted phenotypic correlation $r = 0.356$, the dispersion of subtests scores, which averages at 12.67 %, can be explained by their mutual variation.

We calculated 70.51 % of genetic correlations from the possible number of cases; the correlations varied over a wide range from $r_{gFS \times CC} = -0.679$ to $r_{gFS \times FW} = 0.974$. If the analysis includes only cases of associations between characteristics of language competence, then the lowest genetic correlation $r_{gDCA \times CS}$ will be 0.002. The average weighted coefficient of genetic correlation rg will then equal 0.625. The mutual variability of pairs of different language competence characteristics can be explained up to 39.06 % by of the influence of genetic factors shared by the considered pairs of subtests.

In order to conduct a comparative analysis of groups of twins raised by mothers with medium and high ES, we identified 28 cases of associations between the characteristics related to the Language competence factor. For them, phenotypic and genotypic correlations in both samples were calculated. In the group of twins from families with high maternal ES the average weighted phenotypic correlation r was 0.499, genotypic correlation rg was 0.706 and the determination coefficients were r^2 = 0.249 and rg^2 = 0.498, respectively. In the group of twins from medium ES families, the weighted average phenotypic (r = 0.351) and genotypic (r_g = 0.559) correlations were lower (determination coefficients r^2 = 0.123 and r_g^2 = 0.312, respectively).

We calculated environmental correlations only for 19.23 % of all possible cases. Most of them, as a rule, were characterized by negative and low correlations of subtests *Grouping of concepts and Coding of intent* (inter se and with other subtests). Unfortunately, we were unable to elicit sufficient number of cases of environmental correlations in order to either perform a generalized analysis or to compare environmental correlations for the same cases obtained in samples from high and medium ES groups.

DISCUSSION

Children from families with high maternal ES score better in most language subtests than twins whose mothers have a medium ES. The differences are independent of the zygosity status, which allows uniting MZ and DZ samples for the purpose of studying the structure of phenotypic correlations. The differences in the two split-twin samples, each of which includes one twin from the pair, were reproduced in 7 subtests concerning grammar, morphology, meanings of sentences and words, and working with a text. The result agrees with the data obtained by foreign [8, 10] and Russian [11] researchers.

We have found correlations between ES and the survey data pointing out to some peculiarities in the upbringing of twins. As a whole, the results are consistent with the data obtained from the studies indicating a connection between high ES of parents and their desire to create a rich development-oriented environment for children [5, 12–14]. The present research shows that the same trend is typical for families raising children of primary school age. The results suggest that mother's ES reflects the degree of her subjective activity aimed at using a more individualized approach to the upbringing of each twin. Mothers with high ES seek to create a development-encouraging environment that allows overcoming the excessively close relationship between the twins and helps each child to become an individual. The problem of individualization is one of the most important problems of twin development [19].

It has been found that the structure of associations between Ht subtests changes depending on the maternal ES. Twins from the high ES subgroup have shown relatively strong phenotypic correlations between 10 subtests mainly related to grammar, morphology, sentence meanings and work with a text. These subtests measure language skills related to operating language constructs and not to characteristics associated with thinking or using language for the pragmatic purposes

Table 4. Averaged intra-individual and intra-pair cross-correlations. MZ twins, high ES of mothers

Subtests	SR	PN	SRW	DCA	CIS	CS	CA	GC	AF	VNI	CI	TM
GS	0.714***	0.214	0.652***	0.700***	0.663***	0.634**	0.423	0.136	0.408	0.425	0.266	0.697***
	0.755****	0.203	0.542*	0.532*	0.663***	0.650***	0.618**	0.147	0.387	0.294	0.156	0.727****
SR		0.405	0.505*	0.697***	0.699***	0.668***	0.573*	0.238	0.250	0.398	0.375	0.714***
		0.455	0.537*	0.636**	0.754****	0.731****	0.660***	0.329	0.313	0.083	0.266	0.725****
PN			0.099	0.324	0.429	0.500*	0.546*	0.004	−0.167	0.086	0.221	0.403
			0.157	0.366	0.366	0.486*	0.366	0.136	−0.053	0.060	0.254	0.371
SRW				0.715****	0.568*	0.575*	0.368	0.323	0.489*	0.443	0.200	0.421
				0.694***	0.617**	0.618**	0.609**	0.272	0.431	0.595*	0.129	0.463
DCA					0.656***	0.780****	0.455	0.164	0.398	0.370	0.327	0.424
					0.641***	0.746****	0.666***	0.326	0.369	0.313	0.238	0.544*
CIS						0.627**	0.616**	0.338	0.143	0.268	0.207	0.669***
						0.747****	0.576*	0.159	0.224	0.472	0.489*	0.597*
CS							0.447	0.016	0.369	0.366	0.282	0.505
							0.612**	0.345	0.130	0.281	0.355	0.551*
CA								0.303	0.126	0.225	0.247	0.616**
								0.111	0.276	0.397	0.301	0.503*
GC									0.161	−0.023	0.076	0.288
									0.242	0.341	0.106	0.134
AF										0.204	−0.313	0.220
										0.273	−0.103	0.294
VNI											0.220	0.371
											−0.002	0.168
CI												0.203
												0.233

Note. Top of each cell contains averaged intra-individual cross-correlations, bottom — averaged intra-pair cross-correlation.

of communication. Based on the correlations reproduced in both groups of twins (split-twin groups, one of the pair in each group), we have identified a common linguistic factor called Language competence. On average, 30.03 % of individual differences in the characteristics included into the Language competence factor can be explained by the mutual variability of these characteristics. In the medium ES subgroup the subtests correlations were noticeably lower. A significant percentage of insignificant correlations belong to the associations that subtests excluded from the Language competence factor had inter se and with other subtests. On average, only 12.67 % of individual differences in the characteristics included into the Language competence factor can be explained by the mutual variability of these characteristics. These estimates are approximate, obtained in the generalized analysis of correlation matrices and by calculation of weighted average correlations. With a bigger sample size, it would be possible to use other, more advanced methods of statistical analysis. Thus, the improvement of language skills possessed by children from families with high maternal ES is associated with the increased structural connection between relevant linguistic characteristics.

The results allow deducing a provisional answer to the question whether the nature of phenotypic associations between linguistic characteristics observed in children varies depending on the ES of their mothers. Since not all the pairs of subtests allowed calculation of genotypic correlations, the comparative analysis could only be performed in 28 cases, regarding the structure of genetic correlations in the subgroups of twins raised by mothers with different ES. While in the high ES sample phenotypic differences in the considered Language competence aspects could for the average of about 24.90 % be explained by the mutual variation of these characteristics, in the medium ES group the mutual phenotypic variability for the same subtests describes about 12.32 % of the scores. At that, the first sample had the observed associations explained by the influence of shared genetic factors for the average of about 49.84 %, and in the second sample the contribution of the shared genetic factors to the explanation of the obtained phenotypic correlations was only 31.25 %. There is a reason to believe that maternal ES determines more than just differences in the dynamics of genetic and environmental contributions to the variability of language skills, which has been reported by researchers both abroad [33] and in Russia [32]. This factor determines the differences in the level of dependence of structural interconnectedness between language competencies on the genetic factors shared by them. Following the assumptions of Bronfenbrenner and Ceci's bioecological model and Scarr's ideas [21, 22], it can be assumed that individualized upbringing strategies exercised by mothers with high ES, effected through creation of an environment stimulating language skills development, triggers actualization of the genetic potential underlying the shared linguistic factor. The psychogenetic approach based on biometric statistics does not allow identifying these genes. The present study supports the need for discovery of these genes using methods of molecular genetics.

The results allow conducting a comparative analysis of the contribution of genetic and environmental factors to the structure of the associations between different language competencies only for the subgroup of twins whose mothers have a high ES. On average, in 33 cases for which phenotypic, genotypic and environmental correlations were calculated, a fifth (21.90 %) of individual differences in correlated subtests finds explanation in their mutual variation, with an average of 39.19 % of their mutual variability attributable to the effect of a shared genetic factor. Environmental influences explain only about 7.67 %.

Comparison of intra-individual and intra-pair cross-correlations between different subtests done in the MZ sample allowed tomake a preliminary conclusion: the insignificant contribution of the environmental component of phenotypic correlations between Ht subtests can be explained by the influence of the family environment. In this light and bearing in mind the tendency to individualize the development-oriented environment shown by mothers with high ES, it is necessary to explain negative environmental correlations witnessed in some cases. For example, the highest negative environment correlation $r' = -0.953$ is observed between the subtests *Word formation* and *Imitation of grammatical structures*. With the moderate positive phenotypic correlation ($r = 0.333$) and significant positive genetic correlation ($r_g = 0.596$), environmental influences yield directly opposite results in the development of both abilities. Slight differences between intra-individual and intra-pair cross-correlations between these subtests indicate that we are dealing with the general environment influences that lead to diametrically opposite phenotypic indicators of these abilities. At the same time, a moderate phenotypic relationship remains between the scores of the two considered subtests.

Therefore, we state that individualization of educational influences in families where mothers have high ES boosts children's language skills development, promotes growth of structural cohesion of the characteristics of language competence, ups the role of the genotypic factor and lowers the influence of the family environment in explanations of the nature of this structural cohesion.

CONCLUSIONS

High ES of a mother is a factor in boosting child's language competence that works through creation of a more individualized development-oriented environment (in the context of our twin research: for each twin in a pair, regardless of zygosity status). Higher educational status of mothers means better structural integrity of the aspects of language competence, which is substantially backed by the increased contribution of genetic factors governing language skills. At that, general, mostly family-related, environmental factors make a significantly smaller contribution to the close associations between the aspects of the child's language competence.

The aim of our pilot study was achieved. The conclusions drawn are preliminary. There is a need to conduct studies with larger sample sizes, compiled on the basis of more accurate criteria that take into account all nuances of the family's socioeconomic status. To overcome the limitations inherent in the twin method, it is necessary to conduct research using other psychogenetic methods. Such an approach would allow a generalized analysis that incorporates data on different types of pairs of relatives, as well as application of some more complex genetic and mathematical methods. The results of research efforts as described above would form the basis for molecular genetic studies of etiology of individual differences in language competencies.

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