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Sex-Specific Age-Related Changes of Information Processing Rate Indicators during Childhood and Adolescence

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A B S T R A C T

Despite the relevant findings on non-average information processing rate (IPR) indicators-intelligence relation, and on age-related changes of some of these indicators during aging, the research on sex-specific age-related changes of these indicators during childhood and adolescence are lacking. In a transversal study, 1197 school children (598 girls) aged 8–18 have been individually measured on 5 IPR indicators – two averages (mean_t, median_t) and three non-averages (min_t, max_t, sd_t). The results corroborated the expected non-linear changes of average IPR indicators in the observed developmental period, whereby the sex difference in related developmental patterns was detected: marked age-related decrement in girls ceased at the age of 12, and in boys around the age of 13–14, after which progress in both sexes gradually ceased by the age of 18 and was less pronounced in girls. Generally similar non-linear age-related decrements of non-average indicators were registered, but they showed mutual intensity differences at specific ages and sex difference in developmental patterns was detected, analogously to average indicators. Systematic sex differences in the whole observed period were obtained only in two non-average indicators: girls showed minor sd_t and boys showed minor min_t. In specific age groups, a number of sex differences were obtained that are explainable by two possible mechanisms: earlier maturation in girls and sex bias of the IPR task content. The justifiability of separate, average and non-average, IPR indicators application was corroborated by their distribution form differences, by mutual, predominantly low and medium correlations, by the different intensity of their developmental changes and by their different ability to detect sex differences. For all registered phenomena, the theoretical and/or empirical explanations were offered from the domain of sex specific intellectual, motor and neural development, and it has been shown that non-average IPR indicators do register age and sex differences, which average indicators do not manage to register.

***Key words**: information processing rate, average and non-average indicators, sex differences, age-related changes, childhood and adolescence*

Introduction

The duration of cognitive processes (attention, perception, working memory, decision making, problem solving), measured by reaction time (RT) in related cognitive tasks, is the key variable of cognitive psychology[1–3]. At the same time, it is the most frequent, though inverse measure of the information processing rate (i.e. smaller RT, higher information processing rate), which is a fundamental feature of the human cognitive system and is therefore an integral part of all contemporary models of intelligence[4–7], and human cognitive development[8–12].

In psychological literature, the information processing rate (IPR) is also known as processing speed, mental speed, or cognitive speed and it is a somewhat controversial scientific construct because it is considered one of the several basic components of the human intellect with still existing ambiguities in its strict definition and operationalization[5,13,14]. In the study of intelligence, as well as in the study of human intellectual development and aging, IPR is predominantly expressed by various time measures of performance in very simple cognitive tasks

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with perceptual-motor content[15,16], but it is mostly measured by an individual's average time of task solving (mean or median RT) in a test consisting of a number of such equivalent tasks[15].

Nevertheless, in the last 20 years increasingly emerging research[17–21], and theoretical models of IPR[22–24] clearly show how some elements of individual's RT distribution in a series of IPR tasks (i.e. intra-individual distribution) are not used enough for description of that important feature of the human cognitive system. Therefore, besides the average value of intra-individual RT distribution, other elements of that distribution should be used: variability, extreme results and asymmetry of the distribution. These elements represent IPR indicators that were predominantly used in the research of the IPR-intelligence relation[25–28], but not systematically in all its related phenomena and research fields. For example, studies on sex differences of these indicators were mostly reduced to sex differences in the mean RT[29–32], and to perceptual/clerical speed test scores that produce mean RT per task[33,34], or possibly, to one additional IPR indicator[35–37].

Furthermore, age-related changes of non-average IPR indicators are mostly known for a period of aging and focused on intraindividual variability[20,38,39], but almost nothing is known about other non-average IPR indicators and their changes in the developmental period from childhood to adolescence in which the human intellect is forming, and which – together with the period of aging – forms two integrated parts of the life-span intellectual development.

Additionally, considering empirically tested theoretical explanations of the sex differences in the development of intelligence – which involves IPR development measured by the average performance[40–42] – there is no reason to avoid the research of sex dependent developmental changes of IPR by using non-average IPR performance.

Therefore, this research is focused on sex-specific age-related differences of five basic indicators of human IPR during childhood and adolescence: two average IPR--indicators (mean and median of the individual's RT), IPR stability (standard deviation of the individual's RT), IPR potential (individual's minimal RTs), and IPR failing – the worst IPR performance (individual's maximal RTs).

Subjects and Methods

Subjects

A total of 1301 primary and high school students from Zagreb (Croatia) in the age range from 8 to 18 participated in this study. The preliminary distribution analysis of the observed IPR-indicators showed that, at 72% of all age groups, a significant deviation from normality appeared (mostly because of high outliers, i.e. positive asymmetry). According to the somewhat less rigorous »Schweinle Method« of data screening[43], in each age group the participants with $|z\text{-score}| > 2.57|$ were labeled as outliers (the total of 1% of the highest and/or the lowest results in a normal distribution) and excluded from further analysis. The final sample of 1197 students was examined in the study with age and gender structure shown in Table 1.

Instruments

To record various IPR indicators within children from different socio-economic contexts and wide age range we used non-verbal and non-numerical test (CRD 311) included in electronically designed and computer-controlled chronometrical test battery of psycho diagnostic purpose – CRD System (Complex Reactiometer Drenovac)[44]. The CRD 311 test measures one aspect of perceptual-motor speed: it demands subject's ability of fast visual signal location detecting in a continuous process of its moving on the signal panel (»moving light«), and related fast manual response. The test is performed on the CRD 3 panel (Figure 1) that contains a signal part, consisting of a series of 9 signal lamps (circles), and a command part,

Fig. 1. CRD 3 panel from the psycho diagnostic Complex Reactiometer Drenovac (CRD) test battery.

TABLE 1
NUMBER OF SUBJECTS ACCORDING TO SEX AND AGE

	Age (years)											Sex total
	8	9	10	11	12	13	14	15	16	17	18	
Female	55	48	52	44	40	46	32	78	73	75	55	598
Male	49	42	39	55	40	49	43	70	89	66	57	599
Age total	104	90	91	99	80	95	75	148	162	141	112	1197

consisting of 9 keys vertically located below the signal lamps (squares).

The complete automaticity of the CRD tests does not allow any subjectivity, while the discriminability of the test is very high since response times are measured in milliseconds (ms). Reliability of the test, assessed by internal consistency indicators (split-half method), is high (r_{xx}=0.917) and symptomatic validity – measured by the correlation of the CRD 311 total time of the test solving with psychometric tests of intelligence (Domino test D48, California test of mental maturity) – is high, since the correlations range from –0.33 to –0.38[44], which is completely comparable with the literature on processing/mental speed-intelligence relations[6,7].

Procedure

The examination was organized in a group of two subjects which simultaneously performed the test on one of two CRD instruments, maximally dislocated in the examination room (isolated from external distracters) and separated with an appropriate physical barrier – to minimize possible interference. Every subject was shown his/her appropriate position by the instrument and instructed by his/her examinator. Thereafter they tried the test during a short training sequence with a clear instruction to respond correctly and as fast as possible.

The test CRD 311 consists of 60 substantially equal trials in which one of the signal lamps lights on in an unpredictable manner, and the subject's task is to turn it off by pressing the key located vertically below quickly. The subject has to answer correctly on 60 trials, which means that, if he/she fails in some trial, the same one is repeated until it is answered correctly (i.e. the light »stays« on its position). Alternatively, the proper pressing of the target key automatically starts a new trial (i.e. the light »moves« to another position of the panel).

The CRD system, besides registering response time and accuracy on every trial in the test, automatically calculates the target indicators of our study: IPR potential, IPR stability, IPR failing and the two average IPR-indicators (mean and median).

IPR potential (min_t), presented by mean of three of the shortest times of correct answers in the test, predominantly reflects an optimal functioning of the task relevant parts of an individual's cognitive-motor system (e.g., the activation of optimal neural circuits and motor movements during responding to the task, high level of attention, optimal motivation), but also the minor effects of favorable external factors (e.g., the smallest distance between the signal position of the two successive trials, the absence of distracters).

IPR failing (max_t), presented by mean of three of the longest times of correct answers in the test, predominantly reflects the least optimal functioning of the task relevant parts of an individual's cognitive-motor system, but also the minor effects of unfavorable external factors (e.g., the longest distance between the signal position of the two successive trials, occurrence of uncontrollable external distracters).

Calculating min_t and max_t as an average of the three extreme values was needed to raise the reliability of these indicators: to minimize the effects of random anticipation of signal position and related extremely fast reaction (by min_t) and the effects of external factors (by both min_t and max_t).

IPR stability (sd_t), presented by standard deviation of RTs in all correct answered trials of the test, predominantly reflects instability or non-systematic fluctuations of the individual's cognitive-motor system during successive trials (e.g., fluctuations in attention and motivation, activation of more or less non-optimal neural circuits and motor movements), but also the minor effects of the above mentioned external factors.

Average IPR (mean_t, median_t), presented by mean, or median of response times in all correctly answered trials in the test, reflects a kind of superposition of an individual's IPR potential, stability and failing. These two measures are well established in previous studies of IPR developmental changes, although it is clear that, due to the well-known positive asymmetry of individual RT-distribution[15,18,19,25,26,28,45], median_t is more appropriate than mean_t.

Statistics

Data were analyzed by means of descriptive and inferential statistical procedures (normality and skewness tests, ANOVA and related tests, independent samples t-test, Pearson correlations, Kruskal-Wallis test) adjusted to the obtained distributions of particular age cohort results. After the exclusion of outliers, the results of an average of 24% of the age groups (23.6% at females and 25.4% at males) showed significant deflection from the normal distribution, 82% of them having positive asymmetric distributions (Table 2). This mostly justified using mean ($\overline{X}$) and standard deviation (SD) for description of the age group IPR, otherwise median (C) and the interquartile range (q) are suggested. Considering that the most asymmetric deflections from normality showed sd_t (4 age groups in females and 3 in males), it becomes clear that these deflections could hardly be avoided: sd_t is the square root measure of the sample variance, which is known to be distributed according to χ^2-distribution – positively skewed distribution. The similar stands for positive asymmetry of max_t, which is highly partially correlated with sd_t (r=0.883, df=1194, p<0.01), with the age partialized out.

To check whether the subjects disobeyed the instructions on maximal accuracy while performing the test, we analyzed possible speed-accuracy trade-off effect. Nevertheless, the number of errors in expected 60 trials of the test (that in all age-sex groups had median value 0 and maximal value less than 2) and partial correlations of error number with different IPR indicators controlling for age (that showed maximal value of –0.149 in females min_t, while it did not show any significant correlation in males) justified the absence of this effect.

The standard statistical package SPSS for Windows, version 21.0 (IBM Corporation, New York, USA) was used in the statistical calculations.

Results

The sex-specific age-related changes of the five IPR--indicators are presented in Figures 2–6. Additional statistics, needed for describing relevant properties of indicators distributions, are presented in Table 2.

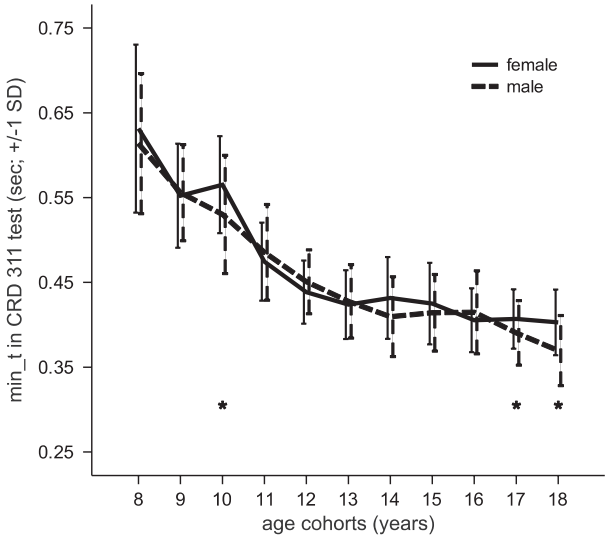

*Fig. 2. Sex-dependent age-related differences in magnitude and variability of IPR potential (min_t) expressed by group means ($\bar{X}$) and standard deviations (SD) for 8 to 18 years old boys and girls. * – significant sex difference in group mean, $p<0.05$.*

Sex-specific, age-related changes of IPR indicators magnitude

Figures 2–4, together with the tests of IPR indicators magnitude changes – conducted by two-way ANOVAs (age*sex), and then by two separate one-way ANOVAs (for each sex) with related Dunnet T3 post hoc tests (Tables 3a–3e) – clearly show that the magnitude of min_t, max_t and sd_t nonlinearly decreases with age, but with a somewhat different pattern for girls and boys:

- in girls, it strongly decreases until the age of 12 (min_t and max_t), or barely 11 (sd_t) and then it decreases much slower (max_t) or stagnates (min_t and sd_t);
- in boys, it strongly decreases until the age of 13–14 (min_t and max_t) or barely 12–13 (sd_t) and then it decreases much slower (min_t) or stagnates (max_t and sd_t).

In this general trend, some local deflections are detectable:

(1) in girls, at the age of 9–10, developmental stagnation of all non-average indicators occurs (Tables 3a–3c, Figures 2–4);

(2) in boys, at the age of 10–12, developmental stagnation on max_t and sd_t occurs (Tables 3b and 3c, Figures 3 and 4)

(3) in both – boys and girls, at the age of 14–15 – insignificant tendency to max_t and sd_t increment occurs (Figures 3 and 4).

An additional finding of these analyses – visible in Tables 3a–3e – is the weakest age-related decrement of IPR stability (sd_t).

Figures 5 and 6 and related ANOVAs – including Tables 3d and 3e – show that the general trend of age-related changes by the average IPR indicators (mean_t and

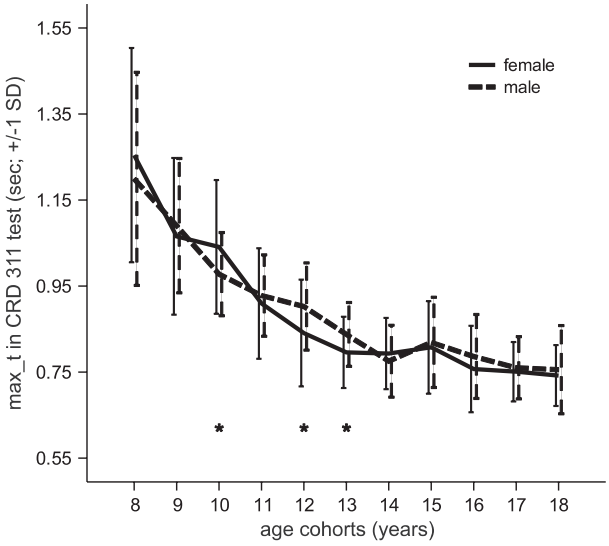

*Fig. 3. Sex-dependent age-related differences in magnitude and variability of IPR failing (max_t) expressed by group means ($\bar{X}$) and standard deviations (SD) for 8 to 18 years old boys and girls. * – significant sex difference in group mean, $p<0.05$.*

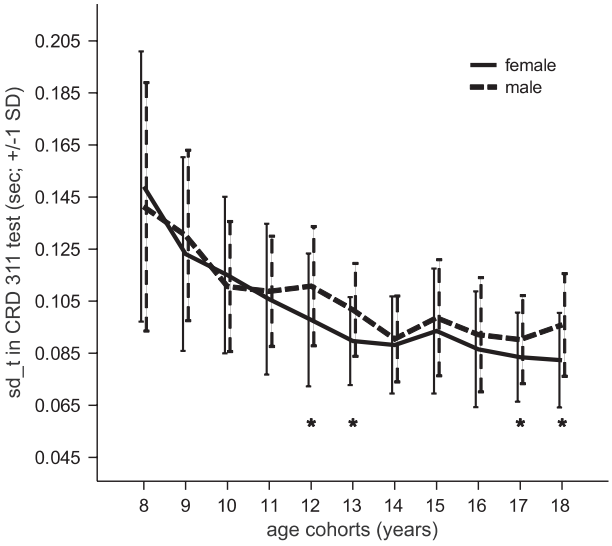

*Fig. 4. Sex-dependent age-related differences in magnitude and variability of IPR stability (sd_t) expressed by group means ($\bar{X}$) and standard deviations (SD) for 8 to 18 years old boys and girls. * – significant sex difference in group mean, $p<0.05$.*

TABLE 2
ADDITIONAL DESCRIPTIVE STATISTICS OF THE 5 IPR INDICATORS FOR THE 11 AGE GROUPS IN BOTH SEXES

		Min_t (sec)				Max_t (sec)				Sd_t (sec)				Mean_t (sec)				Median_t (sec)			
	Age	C	q	CV	skew	C	q	CV	skew	C	q	CV	skew	C	q	CV	skew	C	q	CV	skew
Female	8	0.61	0.131	15.69	0.361	1.19*	0.343	19.85	*0.892**	0.14*	0.072	34.84	*0.917**	0.80	0.125	13.3	0.157	0.78	0.143	13.64	0.220
	9	0.55	0.081	11.12	0.267	1.03	0.257	17.10	0.659	0.12*	0.042	30.20	*1.190**	0.71	0.101	11.1	0.547	0.69	0.104	11.04	0.481
	10	0.57	0.090	10.11	0.169	1.02	0.210	14.94	0.592	0.11*	0.041	26.16	*1.046**	0.72	0.106	9.4	0.165	0.70	0.115	9.15	0.245
	11	0.47	0.066	9.70	–0.046	0.91	0.177	14.15	0.223	0.10	0.031	27.42	0.239	0.61	0.076	8.7	0.592	0.59*	0.068	9.13	*0.729**
	12	0.43	0.057	8.51	0.254	0.82	0.182	14.76	0.387	0.10	0.042	26.13	0.095	0.57	0.070	8.4	0.130	0.55	0.066	8.91	0.042
	13	0.43	0.045	9.58	0.004	0.79	0.129	10.43	0.432	0.09	0.024	18.84	0.322	0.55	0.049	7.1	0.413	0.54	0.054	7.45	0.453
	14	0.43	0.084	11.18	0.372	0.80	0.141	10.43	–0.122	0.09	0.031	21.17	0.232	0.53*	0.052	9.1	0.746	0.51*	0.056	10.18	*0.834**
	15	0.43	0.056	11.32	0.251	0.80*	0.138	13.33	*0.880**	0.09*	0.033	25.64	*0.620**	0.55	0.075	8.7	0.035	0.54	0.074	8.93	0.113
	16	0.40	0.050	9.28	0.477	0.75*	0.132	13.29	*0.911**	0.09	0.029	25.71	0.347	0.52*	0.047	7.7	*0.671**	0.50*	0.053	7.84	*0.692**
	17	0.41	0.046	8.61	0.060	0.74*	0.111	9.19	*0.709**	0.08	0.025	20.50	0.468	0.53	0.049	6.4	0.214	0.50	0.054	7.19	0.146
	18	0.40	0.039	9.63	–0.046	0.75	0.105	9.55	0.044	0.08	0.024	22.05	–0.180	0.51	0.045	6.0	0.450	0.50	0.051	7.05	0.592
	Age	C	q	CV	skew	C	q	CV	skew	C	q	CV	skew	C	q	CV	skew	C	q	CV	skew
Male	8	0.61	0.130	13.46	0.397	1.14*	0.194	20.67	*2.043**	0.13*	0.041	33.78	*1.828**	0.79*	0.126	13.10	*1.433**	0.76*	0.125	12.28	*1.279**
	9	0.56	0.077	10.21	–0.489	1.08	0.234	14.32	0.205	0.13	0.050	25.13	0.365	0.74	0.087	9.55	–0.487	0.72	0.104	9.97	–0.645
	10	0.53	0.114	13.15	0.445	0.96*	0.151	9.90	0.633	0.11	0.036	22.59	–0.036	0.69	0.107	9.42	0.599	0.67	0.095	10.16	0.413
	11	0.49	0.082	11.62	–0.140	0.92	0.152	10.20	0.250	0.11*	0.028	19.47	*0.647**	0.64*	0.109	9.51	–0.050	0.62*	0.121	9.90	0.026
	12	0.45	0.050	8.36	0.662	0.90*	0.146	11.22	*0.937**	0.11	0.028	20.67	0.470	0.60*	0.048	7.02	*0.743**	0.58*	0.051	7.23	*0.795**
	13	0.43	0.052	10.12	–0.432	0.84	0.099	8.85	0.163	0.10	0.022	17.53	0.208	0.58	0.048	6.91	0.366	0.56	0.054	7.83	0.328
	14	0.39*	0.048	11.50	*1.276**	0.78	0.116	10.78	0.426	0.09	0.024	18.24	0.555	0.53	0.060	8.67	0.685	0.52	0.064	9.15	0.653
	15	0.41	0.066	10.91	0.380	0.82	0.157	12.82	0.158	0.10	0.029	22.62	0.395	0.54	0.059	8.31	0.167	0.52	0.068	8.58	0.280
	16	0.42	0.075	11.80	0.231	0.78	0.153	12.42	0.286	0.09	0.029	23.83	0.272	0.53*	0.072	9.09	0.426	0.51	0.073	10.04	0.376
	17	0.39	0.053	9.74	0.038	0.75	0.085	9.53	0.421	0.09*	0.022	18.76	*0.736**	0.51	0.057	6.49	0.177	0.50	0.055	6.74	0.196
	18	0.37	0.046	11.18	0.479	0.77	0.133	13.58	0.183	0.10	0.025	20.59	–0.128	0.50	0.061	9.63	0.115	0.47	0.060	10.14	0.383

(1) *C* – median, *q* – interquartile range, *CV* – coefficient of variation %, *skew* – skewness index
(2) C*- significant deflection from normal distribution; *skew** (written italic and with*) – significant asymmetry of the distribution, i.e. skewness

TABLE 3a
RESULTS OF DUNNETT T3 POST HOC TESTS FOR AGE COMPARISONS OF MIN_T FOR BOTH SEXES

← Post hoc test among ages (male) ←	→ Post hoc test among ages (female) →										
	8	9	10	11	12	13	14	15	16	17	18
8		**	**	**	**	**	**	**	**	**	**
9	**			**	**	**	**	**	**	**	**
10	**			**	**	**	**	**	**	**	**
11	**	**			**	**	*	**	**	**	**
12	**	**	**	*					**	**	**
13	**	**	**	**							
14	**	**	**	**	**						
15	**	**	**	**	**						
16	**	**	**	**	**						
17	**	**	**	**	**	**			*		
18	**	**	**	**	**	**	**	**	**		

* p<0.05; **p<0.01

TABLE 3b
RESULTS OF DUNNETT T3 POST HOC TESTS FOR AGE COMPARISONS OF MAX_T FOR BOTH SEXES

← Post hoc test among ages (male) ←	→ Post hoc test among ages (female) →										
	8	9	10	11	12	13	14	15	16	17	18
8		**	**	**	**	**	**	**	**	**	**
9				**	**	**	**	**	**	**	**
10	**	*		**	**	**	**	**	**	**	**
11	**	**				**	**	**	**	**	**
12	**	**							*	**	**
13	**	**	**	**							*
14	**	**	**	**	**	*					
15	**	**	**	**	**					**	**
16	**	**	**	**	**	*					
17	**	**	**	**	**	**		*			
18	**	**	**	**	**	**		*			

* p<0.05; **p<0.01

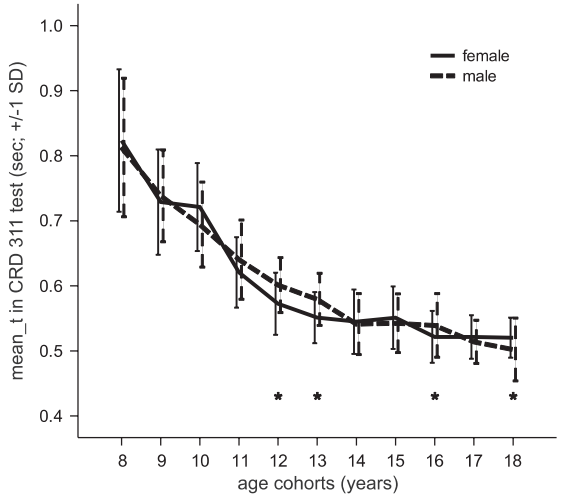

*Fig. 5. Sex-dependent age-related differences in magnitude and variability of mean IPR performance (mean_t) expressed by group means (X) and standard deviations (SD) for 8 to 18 years old boys and girls. * – significant sex difference in group mean, p<0.05.*

median_t) is formally identical, but more pronounced than the one for non-average indicators. On the other hand, the local deflections are remarkably less evident and are reflected in both indicators stagnation at the age of 10 (only for girls), and at the age of 15 (for both sexes).

The findings presented in the figures – that are additionally supported by median values of the Table 2 – are confirmed by basic ANOVA statistics: out of 5 conducted two-way ANOVAs, 4 of them corroborate sex differentiated age-related decrement of IPR indicators, which means that interactional age*sex effect is significant by all IPR indicators but sd_t: $F_{\mathbf{X^-\_t}}=2.76$ ($p<0.01$), $F_{\mathbf{median\_t}}=2.56$ ($p<0.01$), $F_{\mathbf{min\_t}}=2.87$ ($p<0.01$), $F_{\mathbf{max\_t}}=2.17$ ($p<0.05$), $F_{\mathbf{sd\_t}}=1.58$ ($p>0.05$); $df_{age*sex}=10$, $df_{error}=1175$.

Although these findings confirm justifiability of the separate observation of IPR indicators age-related decrement for every sex, they should be taken with caution because of the unfulfilled prerequisite ANOVA assumption – heterogeneity of variance. Therefore, we added to separate ANOVAs (for boys and girls) the findings of associ-

TABLE 3c
RESULTS OF DUNNETT T3 POST HOC TESTS FOR AGE COMPARISONS OF SD_T FOR BOTH SEXES

← Post hoc test among ages (male) ←	→ Post hoc test among ages (female) →										
	8	9	10	11	12	13	14	15	16	17	18
8			**	**	**	**	**	**	**	**	**
9					*	**	**	**	**	**	**
10	*					**	**	**	**	**	**
11	**	*							*	**	**
12	**										
13	**	**									
14	**	**	**	**	**						
15	**	**									
16	**	**	**	**	**						
17	**	**	**	**	**	*					
18	**	**									

* p<0.05; **p<0.01

TABLE 3d
RESULTS OF DUNNETT T3 POST HOC TESTS FOR AGE COMPARISONS OF MEAN_T FOR BOTH SEXES

← Post hoc test among ages (male) ←	→ Post hoc test among ages (female) →										
	8	9	10	11	12	13	14	15	16	17	18
8		**	**	**	**	**	**	**	**	**	**
9	**			**	**	**	**	**	**	**	**
10	**			**	**	**	**	**	**	**	**
11	**	**	**		**	**	**	**	**	**	**
12	**	**	**	*					**	**	**
13	**	**	**	**					**	**	**
14	**	**	**	**	**	**					
15	**	**	**	**	**	**			**	**	**
16	**	**	**	**	**	**					
17	**	**	**	**	**	**		**	*		
18	**	**	**	**	**	**	**	**	**		

* p<0.05; **p<0.01

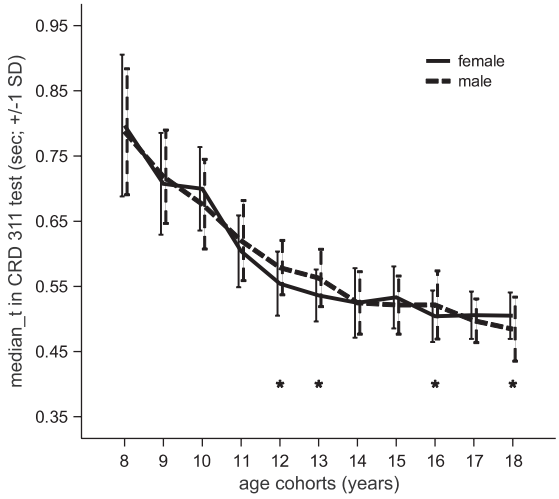

*Fig. 6. Sex-dependent age-related differences in magnitude and variability of median IPR performance (median_t) expressed by group means ($\overline{X}$) and standard deviations (SD) for 8 to 18 years old boys and girls. * – significant sex difference in group mean, p<0.05.*

ated non-parametric procedure – Kruskal-Wallis test (Table 4) – which clearly corroborated age-related decrement of all 5 indicators. These findings, together with the additional ANOVA Partial Eta Squared calculation (part.η^2), emphasized two tendencies:

(1) age-related decrement was the most pronounced for mean_t (part. $\eta^2_{mean\_t}$ equals 0.752 for girls and 0.732 for boys) and its intensity systematically declined over the indicators median_t, min_t, max_t, to the sd_t – where it was the least pronounced (part.$\eta^2_{sd\_t}$, for girls and boys, equals 0.337 and 0.278, respectively);

(2) age-related decrement of IPR indicators is somewhat more pronounced in girls than in boys (the above mentioned part.η^2 data, whose sex relation stands for the rest of IPR indicators) – which is probably the result of girls more intensive age related interindividual variability decrement (Table 5) and of girls' more intensive IPR magnitude development in the observed period (where age-related IPR changes in boys do not reach their ceasing, but in girls they do).

TABLE 3e
RESULTS OF DUNNETT T3 POST HOC TESTS FOR AGE COMPARISONS OF MEDIAN_T FOR BOTH SEXES

← Post hoc test among ages (male) ←	→ Post hoc test among ages (female) →										
	8	9	10	11	12	13	14	15	16	17	18
8		**	**	**	**	**	**	**	**	**	**
9	**			**	**	**	**	**	**	**	**
10	**			**	**	**	**	**	**	**	**
11	**	**	**		**	**	**	**	**	**	**
12	**	**	**	**					**	**	**
13	**	**	**	**					**	**	**
14	**	**	**	**	**	**					
15	**	**	**	**	**	**			**	**	**
16	**	**	**	**	**	**					
17	**	**	**	**	**	**		*	*		
18	**	**	**	**	**	**	**	**	**		

* p<0.05; **p<0.01

Sex-specific, age-related changes of IPR indicators interindividual variability

Interindividual variability in all observed IPR indicators continuously decreased from 8 to 13–14 years of age, whereas after it mostly stagnated (Table 2, especially CV). These age-related decrements (in the first part of the observed developmental period) were corroborated by Levene test results from the two ANOVAs (for girls and boys), suggesting somewhat more pronounced decrements in girls (Table 5).

Additional findings on sex differences

Two-way ANOVA main effect of sex clearly shows that girls have greater IPR stability ($F=10.375$, $df_{sex}=1$, $df_{error}=1175$, $p<0.01$), but minor IPR potential ($F=7.744$, $df_{sex}=1$, $df_{error}=1175$, $p<0.01$) magnitude in the whole observed period. As for the rest of the IPR indicators, girls and boys do not differ: mean_t ($F=0.541$, $df_{sex}=1$, $df_{error}=1175$, $p>0.05$), median_t ($F=0.338$, $df_{sex}=1$, $df_{error}=1175$, $p>0.05$), max_t ($F=0.808$, $df_{sex}=1$, $df_{error}=1175$, $p>0.05$).

Ages at which significant sex differences in IPR indicators magnitude emerged pointed to 5 conclusions:

(1) at the age of 12 and 13 girls showed superior performance on all IPR indicators, whereby this tendency was not significant only in IPR potential (Figures 2–6);

(2) at the age of 16 girls outperformed boys in all indicators, but significantly only in the average ones (Figures 5–6) – as a consequence of sex specific stagnation patterns of the non-average indicators after the age of 13 (girls) and 14 (boys) (Figures 2–4);

TABLE 4
RESULTS OF ANOVA AND KRUSKAL-WALLIS TEST OF AGE-RELATED DIFFERENCES OF 5 IPR-INDICATORS FOR GIRLS AND BOYS

		Mean_t	Median_t	Min_t	Max_t	Sd_t
Girls	ANOVA	F=178.25	F=168.32	F=123.60	F=87.25	F=29.88
	Kruskal-Wallis	χ^2=399.1	χ^2=395.2	χ^2=361.0	χ^2=325.8	χ^2=166.3
Boys	ANOVA	F=160.98	F=156.30	F=110.51	F=76.74	F=22.62
	Kruskal-Wallis	χ^2=407.8	χ^2=397.4	χ^2=353.7	χ^2=326.1	χ^2=142.0

Note: All tests are significant at $p<0.01$ and include $df_{age}=10$. ANOVA tests for girls include $df_{error}=587$ and for boys $df_{error}=588$

TABLE 5
RESULTS OF LEVENE TEST OF AGE-RELATED DIFFERENCES OF 5 IPR-INDICATORS VARIABILITY FOR GIRLS AND BOYS

	Mean_t	Median_t	Min_t	Max_t	Sd_t
Levene test-girls	F=14.55	F=12.88	F=13.77	F=17.90	F=13.78
Levene test-boys	F=9.19	F=8.06	F=8.45	F=9.17	F=6.97

Note: All tests are significant at $p<0.01$ and include $df_1=10$. For girls, all tests include $df_2=587$ and for boys $df_2=588$

(3) boys IPR potential superiority became clear at ages higher than 13 (that become statistically significant only after 17 years of age), although they also showed superior IPR potential at the age of 10 – mostly because of isolated girls IPR performance prolongation at this age (Figure 2);

(4) in IPR stability girls outperformed boys at all observed ages except 8 and 10, but significantly only in four age groups from the beginning and from the end of the target adolescent period (Figure 4);

(5) in IPR failing girls outperformed boys in 8 out of 11 observed age cohorts, but significantly at the ages of 12 and 13 (Figure 3); Only at the age of 10 they performed significantly worse than boys.

Discussion and Conclusion

Although the sex differentiated developmental changes of non-average IPR indicators during the school age were the main topic of our study, we, at first, abstracted two groups of findings related to the average IPR indicators, which we considered indicative for developmental changes of this period.

Nonlinear age increment of the average IPR indicators – i.e. decrement of the average RT – during the observed period of childhood and adolescence (with the ceiling at the end of that period), is the first finding of the conducted research that lies in line with the well-known studies of IPR development during childhood and adolescence[9,11,46]. However, important details of that finding are quite similar, except for age-dislocated patterns of the average IPR indicators increment for boys and girls: in girls, the increment ceases around the age of 12, while in boys it noticeably slows down around the age of 13–14 and afterwards keeps on slowly progressing until the end of the target period. Noble et al.[47] obtained similar findings with one difference: the IPR ceilings for both sexes were moved to the older groups – probably because of the greater complexity of the used cognitive task. Such dislocated developmental patterns might emerge from pubertal neuro-motor developmental changes that girls enter approximately one and a half year before boys[48–50], but they also exit earlier – which produces female superiority in mean_t and median_t exactly at the age of 12–13 and, on the other hand, male superiority at the age of 17–18 (because of the prolonged maturation). These patterns, with the opposite sex differences at the beginning and at the end of the observed developmental period of adolescence, also agree with Lynn's model of intelligence development that includes IPR[41,42].

The second group of our findings that lies in line with the previous research[17,18,25,28] corroborates the justifiability of separate analysis of non-average IPR-indicators.

Firstly, the shape of IPR potential distributions (normal at almost all age-sex groups) is significantly different from mutually similar IPR instability and IPR failing distributions (significantly positive asymmetric at 1/3 of the age-sex groups) (Table 2).

Secondly, partial correlations (with the age partialized out) between average IPR indicators and the non-average ones range from 0.341 (between median_t and sd_t) to 0.856 (between mean_t and min_t), while the partial correlations among non-average indicators range from 0.098 (between min_t and sd_t) to 0.883 (between sd_t and max_t), which points to different IPR constructs.

Thirdly, the intensity of average IPR indicators age-related changes is consistently greater than the one of the non-average indicators. This should be a logical finding since non-average indicators are kind of components of the average ones (see above correlations) and the superposition of the samewise components' changes should be greater than the components' changes themselves.

Fourthly, age-independent sex differences, detected only at min_t and sd_t, clearly suggested that non-average indicators could register those sex differences that conventional average indicators could not. Additionally, it explained (at least partially) why mean_t and median_t did not detect age-independent sex differences: they include min_t and sd_t, and these indicators showed the opposite sex differences in the observed developmental period, which annihilate themselves by combining in the average indicator. Similarly, when min_t and sd_t showed same sex differences at specific ages (12, 13, 16 and 18), then mean_t and median_t also showed sex differences at these ages. These findings are indicative since they suggest that, in some way, the average indicators could be substituted with the non-average ones.

However, the key findings of the research are related to non-average IPR indicators and their sex- dependent age-related changes, which are very poorly documented[51,52], so we had to use mostly neuro-motor developmental arguments to explain our results. We predominantly try to explain the obtained nonlinear decrement of IPR potential by maturational processes of the neural system (the relevant parts), such as myelination of neuronal axons and – to a minor extent – synaptic pruning[51,53,54], but also with the maturation of muscular system[55] (prevalently biological determinacy of min_t might be corroborated by normality of its distributions). The developmental decrement of IPR failing is – to a significant extent – explainable by maturational improvement of attentional system[56–58], bound with the growth of resistance to inner and external distracters[59], and by continuous, empirically conditioned development of motor coordination[60,61], especially after its perturbation by pubertal spurt. Nonlinear decrement of IPR instability during childhood and adolescence might be partially explained by the aforementioned attentional system maturational processes and by motor coordination development, while the other explanations might be empirically conditioned, diffuse-to-focal developmental change of the cortical activity pattern[57,62,63], but also a development of average IPR – which is correlated with IPR instability[51].

In the above mentioned general nonlinear decremental trends, the obtained stagnation-deflections of max_t and sd_t in girls (9–10 years) and boys (10–12 years), seemed to be correlated with some factors occurring im-

mediately before the beginning of puberty, which generate more intensive instability and failing of the cognitive-motor system. On the other hand, in sex-specific developmental changes of non-average IPR indicators' magnitude, age dislocation of females and males developmental trajectories is also clearly detected (similar to average IPR indicators), which – at least partially – explained the obtained sex differences at specific ages.

Furthermore, the occurrence of systematic age-related decrement of interindividual variability of all 5 IPR indicators in the period from 8 to 13–14 years (when stagnation started) tells us that children and pubertals, during those 6–7 developmental years, became even more similar in IPR performance – which is an expected finding if we consider that (1) IPR represents the human cognitive system property which intensively maturates till puberty and then fairly slows down its development[9,53,64–66], and (2) different children at different time enter puberty[67–69].

The next important contribution of the research is findings on IPR age-independent sex differences, as well as sex differences at specific ages. We assume that these differences might be explained by two mechanisms: sex differentiated developmental dynamics and sex biased content of the IPR task.

Sex differentiated developmental dynamics, i.e. girls' earlier maturation, may – at least in part – explain their prevalently greater IPR stability (during the observed period) comparing to males. More precisely, IPR stability will be greater if the attentional system is more developed[59], and for this system it is known that – among others – it is located in the frontal and prefrontal lobes of the cortex[70–72], whose maturation is protracted into the third decade of life[73,74]. Since girls enter puberty earlier, during most of its time they should have maturational advantage and therefore, should show superior attentional functioning (i.e. greater IPR stability) over boys. Besides that, IPR stability will be greater if manual movements at particular CRD 311 trials are maximally similar considering the optimization (either neural or muscular) that presents the motor coordination. Since the motor coordination is perturbed with the puberty onset[61] – which starts earlier in girls – the coordination should also be stabilized earlier and better in girls during the greater part of the observed period.

As in the case of IPR instability, pubertal sex differences of IPR failing (max_t) were also simply explained by girls' earlier maturation: girls' greater max_t at the age of 10, and boys' greater max_t at the age of 12–13 should be the result of sex specific action of maturational factors occurring immediately before the beginning of puberty, which generates more intensive instability and failing of the cognitive-motor system firstly in girls and then in boys.

The possible impact of the IPR task content on sex differences is already known from the studies on average IPR performance sex differences, which emphasized the sort of IPR task (or its components) as one of the key sources of the performance sex differences. More precisely, the findings of methodologically fairly different studies suggest that males show better disposition for success in RT tasks with emphasized spatial and motor component[29,55,75], or with visual signal component[31] – and this suggestion is corroborated in a number of studies dealing with sex differences in biological factors (body and brain), as well as in perceptual and motor factors[76]. Furthermore, a greater experience of particular sex in activities that have cognitive-motor demands similar to certain components of the IPR task, should indirectly produce greater efficiency improvement of cognitive-motor system of the target IPR task by means of skill transfer among the tasks[55,77,78]. Finally, Noble et al.[47] reported that any consistent superiority of one sex over the other rarely occurs, except when the task evokes specific motivational or associative processes that are culturally different between sexes, while Yandell and Spirduso[79] pointed out that gender differences in motivational level of the RT task solving are possible, as a consequence of self-fulfilling gender stereotypes about greater/minor efficiency of one gender in particular sorts of cognitive-motor tasks, or its components.

Additionally, it should be emphasized that IPR tasks might consist of distinctly large components (integrated cognitive-motor sequences) in which one sex might outperform the other. Concerning the conducted study, our experience suggested three distinct components of cognitive-motor process included in CRD 311 task solving: (1) detection of visual signal location change (the longest, which might favor males), (2) performance of short range manual movement by which the finger is brought above the target key (second duration length, which also might favor males), and (3) pressing the key with appropriate intensity (the shortest, which might favor females). In line with these presumptions and previous findings on relation between sex differences and IPR task content, at developmental peak (i.e. in the young adult age) males should outperform females in CRD 311 test – and exactly that corroborated the male's higher IPR potential at the age of 17 and 18 from our study. The absence of significant level of this superiority before these ages might be due to compensating effect of female's earlier maturation.

In conclusion, we could say that the conducted research – although it corroborated partially known findings on average IPR age-related changes in the observed childhood and adolescence period – also offered additional proofs and explanations for obvious elements of sex dimorphism in the shapes of the changes, by integrating the findings from human motor, neural and intellectual functioning research. A noticeable part of the argumentation has been based on non-average IPR indicators, which have been shown as biologically more founded and phenomenologically clearer, but also more sensitive to sex differences detection than the average ones. Thereby, non-average IPR indicators justify their application in developmental research.

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SPOLNO SPECIFIČNE DOBNE PROMJENE INDIKATORA BRZINE OBRADE PODATAKA TIJEKOM DJETINJSTVA I ADOLESCENCIJE

S A Ž E T A K

Usprkos relevantnim nalazima o povezanosti inteligencije s neprosječnim pokazateljima brzine obrade podataka (IPR) i o promjenama dijela tih indikatora tijekom starenja, nedostaju istraživanja o spolno specifičnim dobnim promjenama tih indikatora tijekom djetinjstva i adolescencije. U transverzalnoj studiji 1197 školske djece (598 djevojaka) uzrasta 8 do 18 godina individualno je izmjereno 5 indikatora brzine obrade podataka, od čega dva prosječna (mean_t i median_t) i tri neprosječna (min_t, max_t i sd_t). Rezultati su potvrdili očekivane nelinearne promjene prosječnih IPR indikatora u promatranom razvojnom razdoblju, pri čemu je uočena spolna razlika u pripadnim razvojnim obrascima: izrazito dobno smanjenje kod djevojaka prestaje oko 12. godine, a kod dječaka oko 13–14 godina, nakon čega napredak kod oba spola postupno prestaje do 18. godine te je manje izražen kod djevojaka. Zabilježena su generalno slična nelinearna dobna smanjenja neprosječnih indikatora, ali su pokazala međusobne razlike u intenzitetu kod određenih dobi te je uočena spolna razlika u razvojnim obrascima, analogno prosječnim indikatorima. Sustavne spolne razlike na cijelom promatranom razdoblju dobivene su samo kod dva neprosječna indikatora: djevojke su pokazale manji sd_t), a dječaci manji min_t. Kod pojedinih dobnih skupina dobiven je niz spolnih razlika koje je moguće objasniti s dva mehanizma: ranijim sazrijevanjem djevojaka i spolnom pristranošću sadržaja IPR zadatka. Opravdanost zasebne upotrebe neprosječnih i prosječnih IPR indikatora potvrđena je razlikama u obliku njihovih raspodjela, u međusobnim prevladavajuće niskim i srednjim korelacijama, u različitom intenzitetu njihovih razvojnih promjena te različitoj mogućnosti detektiranja spolnih razlika. Za sve zabilježene fenomene ponuđena su teorijska i/ili empirijska obrazloženja iz područja spolno specifičnog intelektualnog, motoričkog i neuralnog razvoja te se pokazalo da neprosječni IPR indikatori registriraju dobne i spolne razlike koje prosječni indikatori ne uspijevaju registrirati.