# Association between Second to Fourth Digit Ratio with Handwriting Quality and Speed among Elementary School Children

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## Abstract

### Background

Genetic impacts on handwriting legibility and speed, especially in early childhood, are not well understood. The present study used a 2D:4D ratio as a biological marker to investigate the associations between genetic factors with quality and speed of handwriting among the elementary school children.

*Materials and Methods:* The present study used a comparative-correlational method. Participants included 109 boys and 114 girls attending second and third grades in regular elementary schools in 2019 in Golestan province, Iran. The Persian Handwriting Assessment Tool (Havaei et al. 2017), and photocopy method were used to measure handwriting performance and 2D:4D ratio, respectively. Legibility in copying and dictation, as well as the speed of handwriting, were assessed as dependent variables.

*Results:* The results showed that boys and girls had identical age and education. Moreover, it was revealed that boys had significantly lower 2D:4D ratio in both right and left hands compared to girls (P<.001). Furthermore, a negative association was observed between right 2D:4D ratio with word space in copying (r=-.23, P<.001) as well as a significant positive association between left 2D:4D ratio with word formation (r=.13, P=.04) in the dictation of boys. Additionally, the results indicated a significant negative association between right 2D:4D ratio with word alignment in the dictation of girls (r=-.20, P=.02). No other significant associations were observed between 2D:4D ratio and handwriting performance. Finally, no significant differences were observed between boys and girls in handwriting performance.

### Conclusion

According to the results, the 2D:4D ratio does not positively affect handwriting quality and speed in elementary school children.

*Key Words:* Digit ratio, Handwriting, Legibility, Speed.

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## 1- INTRODUCTION

Writing is considered as an important cognitive-motor skill among children. It requires the integration of psychological, biophysical, and neurological processes that are acquired over time as well as the linguistic processes that interact in the maintenance and processing of verbal materials that should be converted to writing (1-4). Despite modern computer tools for writing, handwriting is still a prerequisite for many classroom activities at school. It has been shown that handwriting is positively associated with academic performance (5). An important question in a previous study on handwriting was whether good handwriting is an acquired or inherent skill. In this regard, the similarities and variations among twins or parent-offspring have been studied. For example, in a behavior-genetic study, 540 identical and fraternal twins (aged 8-18 years) were examined on writing, language, and reading skills. The results showed substantial genetic influences on writing samples and copy.

Moreover, both language and reading were affected by genetic (6). Besides, handwriting samples from 50 families were collected and analyzed according to the degrees of similarities between parent and offspring using a hand magnifier and a stereomicroscope. The findings demonstrated that there was the highest level of similarity between parent and offspring in pen lifts, entry strokes, exit strokes, connecting strokes, alignment and shading and low level of similarity in pressure, diacritic of the letter "t", the loop formed of the letter "e", and diacritic of the letter "i" (7). The studies mentioned above have increased our knowledge of whether handwriting is inherent or not. However, these studies have used only twins or parent-offspring as a sample and did not involve a general sample population. A popular method for studying behavior-genetic components in general sample populations is the measurement of the second-to-fourth (2D:4D) digit ratio. The digit ratio or 2D:4D is the ratio of the length between the second ("index "finger) and fourth ("ring" finger) digits of the hand and represents an individual difference variable putatively related to parental gonadal hormonal (testosterone and estrogen) exposure and is stable over the lifetime (8-11). It has been shown that males typically have smaller 2D:4Ds (i.e., relatively longer fourth digits) compared to females (12). Several studies have demonstrated that 2D:4D ratio is associated with motor abilities in humans (11, 13-14). Therefore, the present study used 2D:4D ratio as a biological marker of fetal testosterone exposure to investigate the associations between prenatal testosterone exposure and quality and speed of handwriting (as a cognitive-motor ability) among children.

To the best of our knowledge, this is the first study that investigated the association between 2D:4D ratio with quality and speed of handwriting. However, the association between 2D:4D ratio handwriting style has been investigated, and it has been shown that 2D:4D ratio is associated with handwriting style in females but not in males (15). According to the results of the studies, as mentioned above, it was predicted that: 1) boys have lower 2D:4D ratio compared to girls; and 2) 2D:4D ratio predicts handwriting performance among children.

## 2- MATERIALS AND METHODS

The present study used a cross-sectional comparative-correlational method.

### 2-1. Participants

Participants included 109 boys (aged 8.39 ± 0.56 years), and 114 girls (aged 8.45 ± 0.68 years) attending second and third grades in regular public elementary schools in Aliabad Katoul city in Golestan

province, Iran, in 2019. The sample size was selected based on the following formula (n > N*X / (X + N − 1), where, X = $Z_{\alpha/2}^2$ * p * (1-p) / $MOE^2$, and $Z_{\alpha/2}$ is the critical value of the Normal distribution at α/2 (e.g., for a confidence level of 90%, α is 0.05 and the critical value is 1.96), MOE is the Margin of Error (5%), p is the sample proportion (50%), and N is the sample population). All children were right-handed and did not use any hearing aid. The protocol was performed based on the Declaration of Helsinki and was approved by the university's institutional review board (ID_code: IR.IAU.AK.REC.1398.012). The parents gave written informed consent.

## 2-2. Handwriting Tool

The handwriting task was adopted from the Persian Handwriting Assessment Tool (PHAT) for elementary school children (16). This tool evaluates writing performance in second and third grades children in elementary school. The authors examined the validity of this instrument and reported internal consistency of 0.84-0.99 for all legibility dimensions. It included demographic and handwriting parts. The demographic part included information such as class, gender, hand-dominant, using eyeglass and hearing-aid, and name of the school. In the handwriting part, children were asked to copy and dictate words on a sheet of paper as accurately as possible.

Legibility dimensions, including formation, space, alignment, and text slant, were assessed for written words. All dimensions of the legibility component were assessed using a five-point Likert scale ranging from very poor to very good. In the copying part, children wrote the words on a paper sheet in which the words were printed on top of the paper, and the child had to copy words as accurately as possible. In the dictation part, an experimenter read the words loudly, and

children were asked to write the words on a paper sheet as accurately as possible. The time (in seconds) took child wrote the words was measured as the speed of handwriting. Two independent judges blinded to children's birthday assessed legibility of handwriting performances. The evaluation was performed using designed specifically for this test (16). Inter-rater reliability for two reviewers was r > 0.70 for all legibility dimensions. Data from the first reviewer was used for further analysis.

## 2-3. Second to Fourth Digit Ratio

In this study, we used the photocopy method to measure 2D:4D ratios. To this end, participants had their hands photocopied. Length of the second (index), and fourth (ring) fingers were measured from photocopies of the surface of the hand using Vernier calipers with a resolution of 0.01mm. Measurements were taken from the top of the finger to basal crease (**Figure. 1**). Where two creases were visible at the base of the digit, the crease proximal to the palm was chosen. The length of the index finger was divided by the length of the ring finger to obtain 2D:4D, and $D_{R-L}$ were calculated as the difference between right and left 2D:4D (17). A team of trained research assistants at the university undertook the measurements.

## 2-4. Ethical Considerations

The Research Ethics Committee of Islamic Azad University, Aliabad Katoul Branch, approved this protocol study (Code: IR/IAU/AK/REC/1398/012).

## 2-5. Data Analysis

Mean and Standard Deviation (SD) were used to describe the research variables. Kolmogorov-Smirnov test was used to assess normal distributions of research variables. The relationship between 2D:4D with quality and speed of handwriting was

investigated using the Spearman used to analyze gender differences on quality and speed of handwriting as well as correlation test. Mann-Whitney U test was 2D:4D digit ratio. The significance level was set at *P*<0.05.



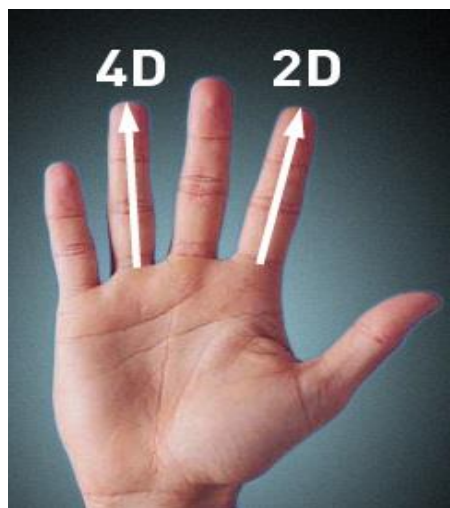**Fig.1**: A schematic view of 2D:4D digit ratio.

## 3- RESULTS

Means and SD of demographic variables, 2D:4D ratio and handwriting performance of children are summarized in **Table. 1**. Regarding age and education, the results showed that boys and girls had identical age and education, indicating that children had similar distributions in two groups. Results of Kolmogorov-Smirnov tests revealed that research variables were not normally distributed. Therefore, we used the Mann-Whitney U and Spearman correlation test for further data analysis. Concerning 2D:4D ratio, results demonstrated that boys had significantly lower 2D:4D ratio in both right and left hands compared to girls (p<0.001). Finally, no significant differences were observed between boys and girls in all dimensions of copying and dictation (all p> 0.05).

**Table-1:** Means of demographic variables, digit ratios, and handwriting of participants.

| Variables | Boys | Girls | Mann-Whitney U | Z | P-value |
|---|---|---|---|---|---|
| Age | 100.72±6.74 | 101.42±8.12 | 6012.00 | -.42 | .675 |
| Education | 2.22±.41 | 2.26±.44 | 5946.00 | -.74 | .455 |
| Right 2D:4D | .959±.014 | .973±.023 | 2878.50 | -6.92 | <.001 |
| Left 2D:4D | .951±.018 | .968±.012 | 2880.50 | -6.92 | <.001 |
| DR-L | .008±.021 | .005±.026 | 4983.50 | -2.55 | .011 |
| Copying | | | | | |
|     Formation | 3.68±.79 | 3.54±.65 | 5734.00 | -1.00 | .31 |
|     Slant | 3.51±.91 | 3.56±1.00 | 6051.00 | -.35 | .72 |
|     Space | 2.77±1.18 | 2.58±1.00 | 5227.00 | -1.01 | .31 |
|     Alignment | 3.22±.84 | 3.06±.96 | 5473.00 | -1.55 | .12 |
|     Speed | 64.24±30.24 | 64.88±29.73 | 6167.50 | -.09 | .92 |
| Dictation | | | | | |
|     Formation | 3.49±.89 | 3.66±.97 | 5550.50 | -1.38 | .67 |
|     Slant | 3.35±1.00 | 3.50±1.19 | 5585.00 | -1.37 | .17 |
|     Space | 2.78±1.05 | 3.05±1.23 | 5451.50 | -1.58 | .11 |
|     Alignment | 3.16±.97 | 3.30±1.02 | 5574.00 | -1.33 | .18 |

2D:4D=second to fourth digit ratio, $D_{R-L}$=Difference between right and left digit ratio.

Results of Spearman correlation tests are presented in **Table. 2**. Regarding copying part of handwriting in boys, the results indicated that there were significant negative associations between right 2D:4D ratio with word space (r = -0.22, p = 0.01) and speed of handwriting (r = -0.23, p = 0.01). These results indicate that low 2D:4D ratio in the right hand is associated with higher quality in word space among boys. Moreover, boys with lower 2D:4D ratio needed more time to write the words on the paper. No other significant associations were observed between right 2D:4D left 2D:4D, or $D_{R-L}$ ratios with other dimensions of copying among boys. In dictation, there was only a significant positive association between left 2D:4D ratio with word formation (r = 0.13, p = 0.04, which indicates that boys with lower

2D:4D ratio had weaker word-formation. No other significant associations were observed between right 2D:4D left 2D:4D, or $D_{R-L}$ ratios with other dimensions of dictation among boys. Regarding the copying part of handwriting among girls, the results indicated that there were no significant associations between right 2D:4D, left 2D:4D, or $D_{R-L}$ ratios with all dimensions of copying. In dictation, there was only a significant negative association between right 2D:4D ratio with word alignment (r = -0.20, p = 0.02), which indicates that girls with lower 2D:4D ratio had better word alignment. No other significant associations were observed between right 2D:4D left 2D:4D, or $D_{R-L}$ ratios with other dimensions of dictation among girls.

**Table-2:** Relationships between digit ratio and handwriting performance based on Spearman correlations.

| | Copying | | | | Dictation | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Formation | Slant | Space | Alignment | Speed | Formation | Slant | Space | Alignment |
| **Boys** | | | | | | | | | |
| Right 2D:4D | r=-.07 p=.44 | r=-.01 p=.84 | r=-.23* p=.01 | r=-.09 p=.31 | r=-.22* p=.01 | r=.02 p=.69 | r=-.00 p=.96 | r=-.06 p=.32 | r=-.08 p=.21 |
| Left 2D:4D | r=.06 p=.52 | r=-.10 p=.27 | r=-.03 p=.70 | r=-.08 p=.38 | r=-.00 p=.98 | r=.13* p=.04 | r=.02 p=.74 | r=.07 p=.25 | r=.03 p=.58 |
| *Dr-1* | r=-.15 p=.11 | r=.03 p=.69 | r=-.11 p=.21 | r=-.05 p=.60 | r=-.08 p=.35 | r=-.07 p=.26 | r=.03 p=.64 | r=-.11 p=.09 | r=-.08 p=.20 |
| **Girls** | | | | | | | | | |
| Right 2D:4D | r=-.04 p=.66 | r=-.11 p=.20 | r=.15 p=.09 | r=.07 p=.43 | r=.11 p=.24 | r=-.18 p=.06 | r=-.17 p=.06 | r=-.10 p=.24 | r=-.20* p=.02 |
| Left 2D:4D | r=.06 p=.47 | r=.08 p=.37 | r=.01 p=.89 | r=-.08 p=.37 | r=.08 p=.36 | r=.03 p=.69 | r=-.04 p=.63 | r=.03 p=.74 | r=.02 p=.79 |
| Dr-1 | r=-.12 p=.18 | r=-.17 p=.06 | r=.02 p=.75 | r=.15 p=.09 | r=-.05 p=.57 | r=-.17 p=.06 | r=-.09 p=.31 | r=-.07 p=.43 | r=-.10 p=.27 |

*p<.05

## 4- DISCUSSION

Genetic influences on handwriting legibility and speed are not well understood. This study used 2D:4D ratio

as a biological marker of fetal testosterone exposure to investigate associations between genetic factors with quality and speed of handwriting in elementary school children. To the best of our knowledge,

this is the first study, which investigates the association between 2D:4D ratio with quality and speed of handwriting. It was hypothesized that: 1. boys have lower 2D:4D ratio compared to girls; 2. 2D:4D ratio predicts handwriting performance in children. Regarding the first hypothesis, the results showed that boys had significantly lower 2D:4D ratio in both rights and left hands compared to girls. These results support our first hypothesis and are consistent with those of previous studies indicating that males have a lower 2D:4D ratio compared to females (8-14). The 2D:4D ratio represents individual differences associated with and organization in the first trimester of gestation, which is critical for the development of the nervous system as well as sexual differentiation of the developing fetus and is stable over the lifetime (8-11, 18-19). As a result, males tended to have a lower 2D:4D ratio compared to females because of exposure to higher levels of testosterone.

Regarding the second hypothesis, the results of this study showed a negative association between right 2D:4D ratio with word space in copying as well as a significant positive association between left 2D:4D ratio with word formation in dictation among boys. Moreover, the results indicated a significant negative association between right 2D:4D ratio with word alignment in dictation in girls. According to the above-mentioned results, we found some associations between 2D:4D ratio and some components of handwriting quality. However, because the results of the present study do not indicate a comprehensive association between right and left 2D:4D ratio with all handwriting quality components in both copying and dictation parts, it seems hard to conclude that 2D:4D ratio is associated with higher quality of handwriting among elementary school children. However, in our opinion, these results do not support our second

hypothesis regarding to handwriting quality. Furthermore, these results are not consistent with those of previous studies (6-7) which found substantial genetic influences on reading and writing quality as well as writing properties such as pen lifts, entry strokes, exit strokes, connecting strokes, alignment and shading. Therefore, further stuides are required to make clear conclusions on the influence of genetics on handwriting quality.

Considering handwriting speed, the results of the present study showed that boys with lower right 2D:4D ratio wrote the words slower unlike girls. Since, to the best of our knowledge, no previous research studied the effects of genetic on handwriting speed, we are not able to compare our results with previous studies. Future studies must examine this issue to make clear conclusions on the associations of 2D:4D ratio with handwriting speed. These findings do not support our second hypothesis as 2D:4D ratio had no positives influence on handwriting speed in elementary school children.

Regarding gender differences, the result of the present study indicated no significant differences between boys and girls on legibility and speed of handwriting. These results are consistent with those of previous study (20) which found that there are no gender differences on handwriting, but are inconsistent with those which found the association between gender differences and handwriting (21, 22). The results of the present study add to the controversy knowledge on the gender differences in handwriting quality and speed. It has been noted that some demographic variables such socioeconomic status, parent education, and attendance in kindergarten might be considered as influential factors on handwriting performance. Gender differences were examined in kindergarten children and it was found that students' socioeconomic status (low-poverty

households vs. high-poverty households) can affect alphabet knowledge, phonological awareness, and spelling (23). However, future studies should consider socioeconomic status and examine its potential moderating role on the gender differences in handwriting performance among Elementary school children.

## 5- CONCLUSION

The present study is, to the best of our knowledge, first to investigate the associations between 2D:4D ratio and handwriting performance (quality and speed) among elementary school children. Our results indicate that 2D:4D ratio was lower among boys compared to girls. Moreover, the results of the present study indicated that 2D:4D ratio has no positive effect on handwriting quality and speed among elementary school children. Additionally, no gender differences were observed in handwriting quality and speed among elementary school children.

Further studies are required to provide clear conclusions on the genetic influences on handwriting quality and speed in children. Furthermore, further stuides should focus on demographical variables such as socioeconomic status, parent educational level, and previous experiences for presenting a clear picture of any gender differences in handwriting performance in Elementary school children. Finally, among the limitations of this study, we assessed handwriting using a qualitative method (rating by two judges). Using digital devices for handwriting and a quantitative assessment may result in a clearer picture of handwriting performance.

## 6- CONFLICT OF INTEREST: None.

## 7- ACKNOWLEDGMENTS

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