# Unveiling Mirror-Writing: Exploring the Phenomenon in Typically Developing Children within the Greek School Context

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Abstract: Mirror-writing has consistently intrigued researchers throughout the years. This study is the first to explore Greek-letter and Arabic-digit reversals from typically developing children within the Greek School Environment. The hypotheses were: (1) Visual discrimination, visual memory, and visual-spatial relationships skills will negatively correlate with the occurrence of character reversals, (2) Left-oriented symbols will be reversed most frequently, (3) Children from year 1 will exhibit fewer reversals than children in nurseries. To test those predictions, 117 children (4.5 to 7.5 years) were recruited from Greek nurseries and primary schools. Character-recognition tasks were conducted, and children's visual-perceptual ability was measured. Moreover, participants produced capital Greek letters and Arabic digits under dictation. Results yielded a significant negative correlation only between visual-perceptual skills and digit reversals in the total sample, suggesting that children with higher visual-perceptual skills tend to produce fewer digit mirrorings, unlike letters. Furthermore, left-oriented characters were significantly mirrored the most. Finally, only digit reversals were significantly reduced by year 1, probably due to the limited knowledge of letters by children in nurseries. Implications, and suggestions for future research are discussed.

Keywords: Greek-Letter Reversals, Character Reversals, Visual-Perceptual Skills, Writing Development, Greek Alphabet, Arabic Digits

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## 1. Introduction

Writing development stands as a pivotal milestone in the educational journey of children, and it is not surprising that many researchers have shown a sustained interest in mirror-writing in recent decades. A major component of mirror-writing concerns "character reversals", a term that refers to letters and digits that are flipped horizontally, in a way that can be clearly read using a mirror (Fischer & Luxembourger, 2018). For more than 140 years this phenomenon has received special attention. Over the years, various explanations have been proposed, some of which have been rejected, while others have been systematically supported by evidence (Fischer, 2022). However, despite the undiminished interest of the scientific community in this phenomenon, mirror-writing in alphabets other than the Latin has been understudied, raising the need for further exploration.

### 1.1 Background and the Rejected Theory of *Motor Hypothesis*

*Mirror-writing* was first reported in 1878 by Buchwald, who observed his patients with right hemiplegia (i.e., paralysis of the right side of the body after injury in the Central Nervous System), writing reversed letters. He suggested that mirror-writing could be manifested only by people writing with their left hand (Fischer, 2022, p. 9). Further developing this idea, Erlenmeyer stated that mirror writing is a result of *Abductive Writing* i.e., writing (with the left hand) from the middle line of the body outwards (Erlenmeyer, 1879). This theory was later named *Motor Hypothesis* (Eager & Fisher, 1932) and was further supported by many researchers such as Ireland (1881), Lochte (1896), Beeley (1918), and Wang (1992), which led to it becoming the dominant theory of the 20th century (Fischer, 2022, p. 26). However, despite the persistent idea that left-handedness is the underlying cause of mirror-writing (Fisher, 2022, p. 15), presently, it is widely disproved by the scientific community (Cubelli & Della Sala, 2009; Fisher, 2022; Hale & Kuh, 1901; Preyer, 1895). It is now entirely accepted that all typically developing children, regardless of lateralization, will exhibit some degree of mirror-writing (Fischer, 2022, p. 12; Schott & Schott, 2004).

### 1.2 The Role of Visual-Perceptual Skills in Mirror-Writing

Recent studies show that although children aged 4–6 years may perceive letters and numbers well, they might reverse them when producing them from memory (Fischer & Luxembourger, 2018). In a study concerning object orientation and memory, Gregory et al. (2011) showed that four to six-year-old children may confuse the orientation of objects and are particularly prone to mistakes when working from memory. Specifically, they presented children with an image of an object and immediately afterward they showed them the image of this object in a red circle among others with various orientations. Then, they asked the children to find the object identical to the one in the red circle (thus with the same orientation). After that, they conducted a similar activity, but this time the object from the initial picture was not highlighted. Children were required to retain it in their memory while searching for the corresponding object with the same orientation among the presented options. Results showed that in the first phase, children answered correctly in 75% of the attempts while in the second, depending on the age, they responded correctly in only 41–61% of the trials. These findings indicate that children between the ages of 4 and 6 may make some mistakes in perceiving the orientation of a form, but these errors rise when memory demands increase. If this notion is correct, one might assume that children, at this age, might make some mistakes concerning the understanding of the orientation of letters but they would experience greater difficulty when producing them from memory.

This hypothesis was tested by Fischer and Tazouti in 2012, who examined 5 to 6-year-old children's ability to copy and write letters and numbers from memory. They observed that children at this age rarely made character reversals when copying, whereas these errors increased when memory was involved. In accordance with these findings, Fischer and Luxembourger (2018) formulated the theory of *Character Reversal in Writing from Memory.* According to this theory, children around the age of 5 can effectively perceive the orientation of characters. However, when these characters are being stored in their memory, information about their orientation is often removed due to a neurophysiological process called *mirror generalization*. As a result, children retain representations of learned symbols in their minds, but without orientation. Consequently, children who mirror-write might make few mistakes in perceiving character orientation, but they mainly produce reversals when they need to recall the character orientation.

A different view of the phenomenon was suggested by McIntosh et al. (2018), who tested 44 children aged 4.6 to 10.3 years. In their experiment, children were presented with a set of correct-oriented letters and were asked to recognize them. Later, participants were asked to write a series of those letters, under dictation. Lastly, they were presented with letters again but this time some of them had the correct orientation while others were reversed, and they were asked to choose the correct ones. Results revealed that there was a strong significant correlation ($r = .67$, $p < .01$) between written letter reversals and orientation recognition errors. The researchers interpreted the results stating that mirror-writing is strongly linked to children's ability to recognize orientations in relation to some reference object, in other words, to their visual-spatial relationships skills. However, this interpretation should be judged with caution. Not only were the letters familiar symbols to the children and so they needed to recall the correct orientation from memory, but also at the beginning of the experiment, the correct letters were presented to children, with the result that visual memory was potentially examined more than the visual-spatial relationships skill. It can be argued that those results point us back to the association of recalling orientation with mirror-writing. However, as no published study was found measuring visual-perceptual skills (e.g. visual memory, visual-spatial relationships) and exploring their link with mirror-writing, further research should focus on investigating that association utilizing unfamiliar symbols.

### 1.3 Relationship Between Character Orientation and Frequency of Reversals

The theory of *Character Reversal in Writing from Memory* (Fischer & Luxembourger, 2018) suggests a rationale for why children perform reversals but does not explain why some characters are mirrored more frequently than others. This gap could be covered by the Statistical Learning theory (Treiman et al., 2014) or the *Implicit Right-Writing* theory (Fischer & Luxembourger, 2018). The former theory describes that when children improvise the orientation of a symbol, they are more likely to write it towards the orientation that they have observed as the most frequent in written letters (Treiman et al., 2014). In contrast, the latter suggests that children are more likely to reverse the unfamiliar characters facing toward the cultural direction of writing (Fischer & Luxembourger, 2018).

Both theories obviously presuppose that characters have an orientation, which contributes to the manifestation of mirror-writing (Treiman & Kessler, 2011; Treiman et al., 2014). Brekle (1997) proposed a rule for determining letters orientation, considering that most Latin letters are formed by a vertical line on the left (called hasta) and some characteristic patterns on the right differentiating the letters between them (called coda), giving them the right orientation (e.g., B, D, E, F, k, r). However, some Latin letters as well as Arabic digits do not follow this rule. The orientation of these symbols was later given by Treiman et al. (2014), who asked 33 adults to determine the orientation of all capital letters. Participants agreed that the only left-facing Latin letters are J and Z while most letters were declared as right-facing. Moreover, some capital letters were perceived as neutral or slightly tilted to the right, e.g., N. These findings were later replicated (Fischer, 2017). Regarding Arabic numerals, in 2017, Fischer asked 148 undergraduate psychology students to state their opinion regarding digits orientation. In this way, the orientation of the Latin letters and the Arabic numerals has been defined, and it remains to explore whether children's mirrorings are more influenced by the most frequently observed character orientation or by the cultural writing direction.

#### Theory of *Statistical Learning*

Treiman et al. (2014) provided an intriguing explanation for why left-facing letters are reversed more frequently in Latin Alphabet. They proposed the *Statistical Learning* theory, suggesting that since most letters in Latin Alphabet are right-oriented, children are more familiar with right-facing letter orientation. As a result, when they are unsure about a letter orientation, they are more likely to write it facing the direction they have observed most often, which in the Latin alphabet is the right (Treiman et al., 2014).

However, Treiman et al. based their theory on letters, which are mostly right-oriented, and did not analyze digits, which are primarily left-oriented. This omission could potentially introduce confusion to the application of this theory, as noted by Fischer (2022).

### Theory of *Implicit Right-Writing*

In contrast, if the theory of *Implicit Right-Writing* is correct, children should reverse more frequently the left-facing characters in cultures where the writing direction is from-left-to-right. This hypothesis was made by Fischer and Tazouti in 2012 and their series of experiments endorsed this theory for both digits and letters. One year later, Fischer (2013) tested children 5–6 years old again on the same hypothesis. Again, his hypothesis was confirmed as the left-oriented digits were reversed by 32–45% of the participants, while the right-oriented digits only by 11–26%. Moreover, Fisher and Koch (2016) tested 166 children when they were 5–6 years old and then tested them again one year later. They observed that left-oriented characters were mirrored significantly more than right-oriented at both testing times. Specifically, they mirrored the left-facing characters at a rate of 39.55% and the right-facing at 9.17%, and one year later at a rate of 11.83% and 5.6%, respectively. Those findings are in line with the results of McIntosh et al. (2018), who found that of all the letter reversals children made, left-facing letters (Z, J) were most often mirrored, at a frequency of 33% and 26%, respectively. Overall, all researchers mentioned concluded that the theory of Implicit Right-Writing seems to be supported by evidence for the Latin alphabet and the Arabic numerals.

Regarding the theory of *Statistical Learning*, Fischer believes that Treiman's explanation does not fully account for the observed phenomenon. He points out that children, when writing from right to left (in experiments writing the Latin alphabet), tend to reverse the right-oriented letters more. This contradicts Treiman's theory, which suggests that children are more likely to reverse left-facing letters because they are less accustomed to them. Therefore, Fischer concludes that if children were truly accustomed to the orientation of letters, they would still have difficulty with left-facing letters, which is not consistent with Treiman's hypothesis (Fischer, 2022, p. 43).

Overall, no study was found to compare the application of those two theories, possibly because in the Latin alphabet, both theories would expect children to mostly reverse the left-oriented letters. Nevertheless, understanding the underlying cognitive functions relating to mirror-writing would provide significant insights into writing and literacy development, inform assumptions regarding other alphabets, and have significant implications for education.

## 1.4 The Fade of Mirror-Writing

It is currently commonly accepted that almost all typically developing children will manifest mirror writing at some stage of their development. An interesting question arises: when does this typical phenomenon fade out? Fisher and Koch (2016) tested 166 children twice, with one-year interval, and stated that children aged 5–6 years performed significantly more character reversals than children aged 6–7 years. More specifically, in the first case, 21.35% of the characters were reversed whereas in the second 8.57%. Some years later, Goebel et al. (2019) showed again that children in British year 1 (ages 58–80 months) manifest less mirror-writing than children in reception (ages 49–75 months). In reception children reversed 22.22% of the digits and 14.31% of the letters while in year 1, 7.01% and 2.62%, respectively. Those findings suggest that by the age of 7 years old, the occurrence of this phenomenon declines sharply.

### 1.5 Mirror-Writing Across Different Alphabets and Populations

As described above, mirror-writing in typically developing children has long captured the interest of researchers, who have proposed various theories to explain its underlying mechanisms. However, although this phenomenon has been investigated over the years, it remains significantly understudied in non-Latin alphabets, and largely focused on other populations. For instance, mirror-writing in the Chinese alphabet has been explored in children with intellectual disabilities (Wang, 1992), typically developing children (Wang, 1986), typically developed adults (Wang, 1986), patients with cerebral vascular diseases (Wang, 1986), stroke patients (Wang, 1992), Parkinson's patients (Wang et al., 1995), and typically developed elderly people (Wang et al., 1998). In the Japanese alphabet, mirror writing has been investigated in patients with cerebral vascular disease (Sato, 1979), and in elderly patients with dementia (Kuzuya et al., 1991), while in the Korean alphabet, it has been studied in a patient with a left basal ganglia lesion (Kim et al., 2008). This demonstrates that research on mirror writing is not limited to the Latin alphabet, but it is still rarely studied in other alphabets, particularly in typically developing populations. Additionally, to the best of our knowledge, no studies have examined the phenomenon of mirror writing in the Greek alphabet to date, especially in typically developing children. This underscores a significant gap in the literature, making the investigation of Greek letter and Arabic numeral reversals in typically developing children attending Greek schools of paramount importance.

### 1.6 Summary

In summary, mirror-writing in typically developing children is a phenomenon that, while it has been explored, still provokes some controversy within the scientific community regarding the primary factors that contribute to it. Over the years, researchers have suggested various phenomena to be the cause of the manifestation of reversals. This include factors such as handedness, which has already been disproved, as well as various visual-perceptual skills. Additionally, studies seem to focus not only on the characteristics of children that lead them to mirror-write but also on the properties of the characters (e.g. orientation) that make them more prone to be reversed. Regardless of the underlying factors of this phenomenon, it seems that as children grow from the age of 5 to the age of 7, mirror-writing decreases. Considering the gap in literature regarding mirror-writing in the Greek alphabet, it becomes crucial to investigate the phenomenon as well as the factors that may contribute to it, as this manifests in Greek letters and Arabic numerals in Greek schools.

### 1.7 Current Study and Hypotheses

To the best of available knowledge, this is the first study exploring mirror-writing of Greek-letter and Arabic-digit reversals in typically developing children in Greek nurseries and primary schools. Previous studies have explored the relationship between visual-perceptual skills and mirror-writing, using mostly copying and recalling-from-memory writing tasks. The current study measures visual-perceptual skills using a standardized assessment tool and explores their association with character reversals. Furthermore, the influence of orientation on the frequency of 1. character reversals as well as the fade of the phenomenon will be examined.

The following hypotheses within the Greek school context will be investigated:

(1) Higher visual-perceptual skills (visual-spatial relationships, visual memory, visual discrimination) will be associated with fewer Greek-letter and Arabic-digit reversals.

(2) Left-oriented symbols will be reversed more than right-oriented symbols.

(3) Children in year 1 will perform fewer character reversals than children in nurseries.

## 2. Methods

This study followed a quantitative approach as we were interested in finding objective, measurable, and generalizable results (Bhandari, 2022). The research project was organized and conducted under the auspices of the University of York in England. Approvals for this research were given by the Departamental Ethics Committee of University of York, England and the Directorate of Primary Education of Heraklion, Greece.

### 2.1 Selection of Education Level

Regarding the Greek education system, children are required to attend nursery from the age of 4 until approximately the age of 6. There, they are usually exposed to written numbers and letters through various activities, and they are very often asked to copy or write their names. Later, in year 1, which they attend from approximately 6–7 years old, they are thoroughly taught how to write and read (European Commission, 2022). Considering this, it was decided to recruit participants both from nurseries and year 1 of primary schools.

### 2.2 Selection of Greek Letters and Clarification of Their Orientation

Greek alphabet consists of 24 uppercase and 25 lowercase letters (The uppercase letter "Σ" is linked to two lowercase letters "σ" and "ς"), and the direction of writing is left-to-right. The present research examined the non-symmetrical capital Greek letters (Β, Γ, Ε, Ζ, Κ, Ν, Ρ, Σ) and the letter Υ. Following the rule of Brekle (1997) mentioned above, most

Greek letters mentioned are formed with the hasta + coda structure, giving them the right orientation (Β, Γ, Ε, Κ, Ρ). The only letters that do not follow that rule are: "Z" (previously classified as a left-oriented), "N" (already categorized as slightly right-oriented) and "Σ" (which will be classified as right-oriented because the lines at the left resemble Brekle's "hasta" form). Uppercase letters were chosen due to their early introduction and frequent teaching in nursery settings for children's copying and writing. Additionally, they are widely regarded as easier for children to learn (Elniplex, 2019; Theodoridou, 2024) and therefore it was assumed that children in nursery settings, who have not yet been formally instructed in writing, might find them easier to produce. In conclusion, characters examined comprised the following categories: right-facing letters (Β, Γ, Ε, Κ, Ν, Ρ, Σ), left-facing letter (Z), the symmetrical letter (Y), right-facing digits (4, 5, 6), left-facing digits (1, 2, 3, 7, 9), and the symmetrical digit (8).

## 2.3 Participant Characteristics

Prior to recruiting participants, comprehensive information forms were provided to both headteachers and parents of children attending all the selected schools, outlining the nature of the research and the rights afforded to participants. Participants were assured that their involvement was entirely voluntary, with the option to decline or withdraw from the study at any point without facing repercussions. Written informed consent was obtained from headteachers and parents prior to testing, while oral assent was secured from teachers and children. To ensure confidentiality, participants were pseudonymized by assigning them a code instead of a name, and all raw data, including the file containing participant names, was securely stored in a locked facility in Greece, accessible only to the researcher. As stated on the information sheet, the pseudonymized data were exclusively accessible to the small research group of three persons. Furthermore, children received a debriefing at the study's conclusion, where they were informed that the activities aimed to understand common errors encountered during the writing learning process, and they were given a sticker to remember this participation.

The convenience sample consisted of 117 Greek-speaking children aged 4.5 to 7.5 years old who were attending Greek nurseries or year 1. They were recruited from six nurseries and five primary schools with different socioeconomic backgrounds from easily approached areas in the city center of Heraklion, in Greece, between April and May 2023, shortly before the end of the academic year.

As many young children from nurseries produced a limited number of letters, it was decided to exclude the data from the children who did not recognize three or more letters or digits. Hence, the entire process commenced with a "pre-test phase" designed to assess the children's understanding of characters. When a child knew enough numbers but no letters, data from letters were deleted but data from numbers were included in the analysis. Subsequently, letters and digits were analyzed separately. For this reason, of the 117 participants, 25 children from nurseries were excluded from the analysis for letter reversals, and three from digit-reversal analysis. Participants' characteristics are presented in Table 1.

*Table 1.* Demographic Characteristics of Participants

| Characteristic | Children in Nursery (N = 57) | | Children in Year 1 (N = 60) | | Full Sample (N = 117) | |
|---|---|---|---|---|---|---|
| | n | % | n | % | n | % |
| Gender | | | | | | |
| Female | 35 | 61.4 | 38 | 63.3 | 73 | 62.39 |
| Male | 22 | 38.6 | 22 | 36.7 | 44 | 37.61 |

*Note.* This table presents the demographic characteristics of participants categorized by their education level. Children were on average 74.57 months old (SD = 10.03) and their age range was 49–95 months. Children from nurseries were on average 66.26 months old (SD = 8.24) with an age range of 49–88 and children from year 1 were on average 81.93 months old (SD = 4.16) with an age range of 76–95 months.

## 2.4 Procedure, Materials Used, and Scoring

The procedure involved a pre-test activity and three different tasks. Children were tested individually, in an empty classroom or a quiet school corner. Each time, the child was sitting opposite the researcher and there was a desk between them. All children's responses were observed by the researcher and recorded in coded form on an A4 sheet, as detailed below. Effort was made to keep the testing environment quiet. The whole testing time for each child was approximately 35 minutes. In the end, the researcher debriefed the child while giving them a sticker for their participation.

### Pre-test Phase: Examining Characters Knowledge

The whole procedure started by demonstrating to children a series of plastic cards with the Arabic digits (1–9) and the Greek capital letters (Β, Γ, Ε, Ζ, Κ, Ν, Ρ, Σ, Υ), individually printed one on each card, in random order. The number 8 and the letter Y were excluded from the analysis because they are symmetrical. Children were asked to name the characters and when they didn't know one, the researcher reminded them of the name. Correct character names or sounds were accepted and were noted in the record sheet coded as (1) known or (2) unknown. The reason that this phase was employed was primarily to exclude from the sample all children who could not recognize (i.e., did not have receptive knowledge of) more than three letters. Secondly, it aimed to quickly remind them of the letters before the writing task, as children in Greek nurseries are not explicitly taught writing but are mostly exposed to letters and digits through play and activities (Ministry of Education and Religious Affairs, Institute of Educational Policy, 2014).

### First Task: Examining Visual-Spatial Skills

In the second activity, children's visual perceptual skills were assessed using a standardized assessment tool of visual perception, the Test of Visual Perceptual Skills 3rd edition (TVPS-3) (Martin, 2006). The whole TVPS-3 consists of eight subtests and is used to assess visual-perceptual skills without the participation of movement in children aged 4–18 years old. Abilities assessed in this study included the visual discrimination skill, i.e. ability to differentiate similar items by their different properties, visual memory skill, i.e. ability to visually recall a form and locate it among others, and visual-spatial relationships skills, i.e. ability to perceive the position of a symbol in space by first perceiving the orientation of their own body. The three subtests employed for this study have undergone rigorous testing, demonstrating high levels of validity and reliability[1]. The administration of those three subtests lasted 5–15 minutes and followed the manual guidelines (Martin, 2006). To engage children more in the task, they were asked to listen to a story that ended by posing those three big "riddles", the subtests. Each of the subtests consisted of 16 different items and when a child responded to four out of five times in a row incorrectly, the testing for the subtest stopped. Raw scores of children's performance was documented on the researcher's record sheet.

### Second Task: Writing the Characters

The last task was a dictation task, repeated three times, where the children were asked to write Arabic digits and Greek letters in a different but consistent order each time (in total 27 capital letters and 27 digits). To make the activity more interesting, symbols were written in white squares on a boat picture, representing boat names, as part of an interesting story. Children who did not know how to write a character were guided to form a cross. Examples of children's writing are depicted in Figure 1.

Each written character was assigned one of the following codes based on correctness, orientation, and case: (1) **Correct** (character matches the expected form), (2) **Cross** (character was a cross indicating the child could not recall it), (3) **Mirrored** (character is reversed), (4) **Correct lowercase** (correct character but in lowercase), (5) **Mirrored lowercase** (correct character but in lowercase character and reversed), (6) **Other/Wrong** (character is incorrect or unrecognizable), (7) **Not given** (character was not provided).

## 2.5 Data Analysis

Codes given for each written character were used to calculate the different variables used later in the data analysis. Those variables were the proportion of mirrored letters (= number of mirrored letters/number of correct and mirrored letters), proportion of mirrored digits (= number of mirrored digits/number of correct and mirrored digits), proportion of right-facing mirrored letters (= number of right-oriented mirrored letters (Β,Γ,Ε,Κ,Ν,Ρ,Σ)/ number of right-oriented correct and mirrored letters), proportion of left-facing mirrored letters (= number of left-oriented mirrored letter (Ζ)/ number of left-oriented correct and mirrored letters), proportion of right-facing mirrored digits (= number of right-facing mirrored digits (1,2,3,7,9)/ number of right-facing correct and mirrored digits) and proportion of left-facing mirroreddigits (= number of left-facing mirrored digits (4,5,6)/ number of left-facing correct and mirrored digits).

Additionally, 14% of the data were double scored by a second rater. Cohen's κ was conducted to explore the agreement between the two independent researchers' scorings. The inter-rater reliability overall was high with an average of κ =.803 indicating almost perfect agreement between the two scorers. More specifically, there was almost perfect agreement between the researchers regarding the number of characters children knew, κ = .916 (95% CI, .763 to 1.069), *p* <. .001. as well as the proportion of mirrored letters, κ = .848 (95%CI, .662 to 1.034), *p* < .001. Regarding the proportion of mirrored digits there was substantial agreement, κ = .644 (95%CI, .415 to .873), *p* < .001.

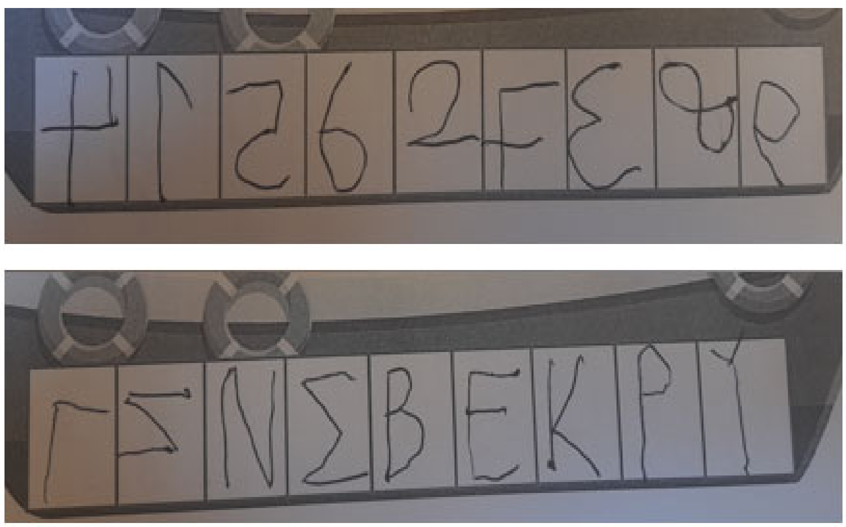

*Figure 1:* Examples of Children's Writing.

*Note*. This picture depicts examples of letter and digit writings by a 55-month-old girl attending a Greek nursery. The child was instructed to write the digits 4, 1, 5, 6, 2, 7, 3, 8, 9 and the letters Γ, Z, N, Σ, B, E, K, P, Y. For the digits, the child correctly wrote 6, 2, and 8, but mirrored the digits 4, 1, 5, 7, 3, and 9 (codes: 3, 3, 3, 1, 1, 3, 3, 1, 3). For the letters, all were written correctly except for the letter Z, which was mirrored (codes: 1, 3, 1, 1, 1, 1, 1, 1, 1). As can be observed, the digit 8 is slightly tilted, and it is open for discussion if it should be classified as correct. Cases like this contributed to the discrepancies in the inter-rater reliability.

To statistically analyze the results, the study employed a variety of designs and statistical methods. All the data were analyzed in IBM SPSS Statistics (IBM Corp, 2020). A correlational design was used to explore the association between the raw scores in the three subtests of the TVPS-3 and the proportions of the reversed letters and digits. Although normality could be assumed because of the central limit theorem (N > 30) (Field, 2009, p. 42), a non-parametric Spearman's rank correlation matrix was used, because of the violation of the assumption of homoscedasticity and the existence of outliers.

Moreover, to explore the effect of the orientation of characters on the number of reversals, a two-way repeated measures ANOVA design was followed. Normality was met by the central limit theorem, the Q-Q plots, and the Skewness and Kurtosis values, and all the other assumptions for this parametric test were also met. For this analysis, the within-subject factors were the proportions of mirrored characters (letters, digits), and the orientation (left, right).

Finally, the researcher examined whether children perform more mirrored symbols in nurseries. Since the data met the normality criteria, a factorial mixed ANOVA design was conducted, with the proportions of reversed letters and digits as dependent variables, and the educational level as between-subject factor. However, the assumption of equality of covariance matrices appeared violated, as Box's M test showed a significant result. Therefore, Pillai's Trace multivariate test was used as a robust statistic for protection against this violation. To investigate the significance of each repeated measure separately, two univariate t-tests were conducted.

### 2.6 Transparency and Openness

Efforts have been made to enhance the transparency and openness of this research, in alignment with the Transparency and Openness Promotion (TOP) guidelines (Nosek et al., 2014). In this section, all the methodological procedures were reported. Specifically, following the APA Journal Article Reporting Standards (JARS) (Kazak, 2018), the author has reported how the sample size was determined, all the data exclusions, all the manipulations, and all the measures that were undertaken in the study. Information about the data availability is given in the Author Note section in the end of this article. This study was not pre-registered.

## 3. Results

Means of proportions of mirrored characters for each letter and digit, categorized by children's education level, are presented in Figures 2 and 3.

### 3.1 Association of Visual-Perceptual Skills with Mirror-Writing

To control the type I error after the multiple comparisons, Bonferroni correction was applied. Therefore, the significance level (.05) was divided by the total number of comparisons (6), adjusting the significance threshold at .008. Descriptive statistics for the variables used in correlational analysis sorted by education level are depicted in Table 2. In general, when disregarding children's education level, the average percentage of mirrored letters was 6% (SD = .09), and of mirrored digits 18% (SD = .22).

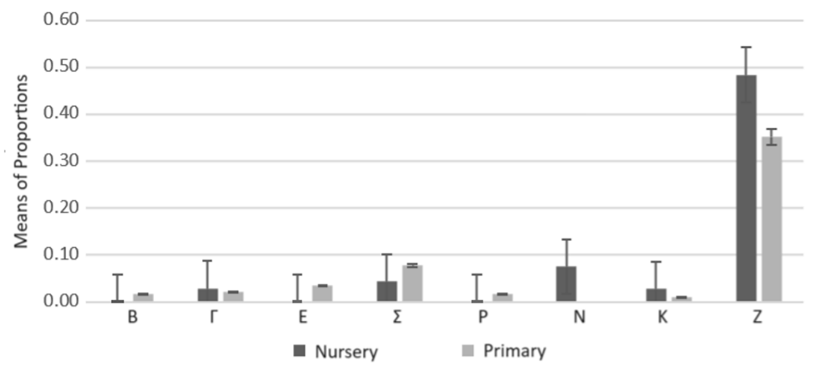


*Figure 2:* Proportions of Mirrored Letters Categorized by Education Level.

*Note*. This bar chart displays the means of proportions of the reversed Greek letters as performed by children in Greek nurseries (N = 32) and year 1 (N = 60). Error bars show standard errors.

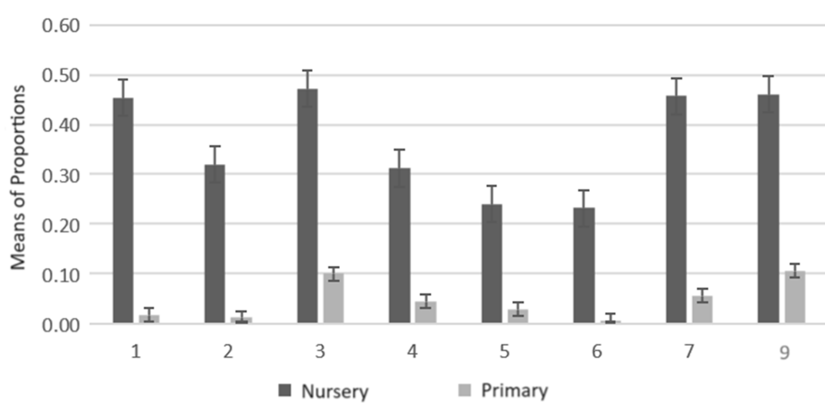


*Figure 3:* Proportions of Mirrored Digits Categorized by Education Level.

*Note*. This bar chart displays the means of proportions of the reversed Arabic digits as performed by children in Greek nurseries (N = 54) and year 1 (N = 60). Error bars show standard errors.

*Table 2.* Descriptive Statistics of the Raw Scores in Visual-Perceptual Skills and Proportions of Mirrored Characters, organized by Education Level

| | Children in Nursery | | Children in Primary | |
|---|---|---|---|---|
| | N | Mean (SD) | N | Mean (SD) |
| Raw Scores in: | | | | |
| Visual Discrimination | 57 | 7.07 (3.56) | 60 | 10.25 (3.42) |
| Visual Memory | 57 | 7.60 (3.35) | 60 | 10.05 (2.62) |
| Spatial Relationships | 57 | 6.46 (4.81) | 60 | 10.50 (4.64) |
| Proportions of: | | | | |
| Mirrored Letters | 32 | .07 (.10) | 60 | .05 (.09) |
| Mirrored Digits | 55 | .33 (.22) | 60 | .04 (.07) |

*Note.* This table presents the descriptive statistics used for the Spearman's rho correlation matrix between the raw scores in visual discrimination, visual memory, and visual-spatial relationships subtests and the proportions of mirrored letters and digits as performed by children in nurseries and year 1.

At first, Spearman's rho correlational matrix involved the proportions of mirrored letters and digits and the raw scores in the three subtests of TVPS-3 from the included children irrespective of the education level, as presented in Figure 4a.

Mirrored digits showed a moderate and statistically significant negative correlation with visual discrimination ($rs$ = -.30, n = 115, $p$ = .001) and a weak to moderate, statistically significant negative correlation with visual memory ($rs$ = -.29, n = 115, $p$ = .002), and visual-spatial relationships ($rs$ = -.28, n = 115, $p$ = .003). In contrast, unexpectedly, mirrored letters presented weak, non-significant, and positive correlations with visual discrimination ($rs$ = .14, n = 92, $p$ = .188), visual memory ($rs$ = .11, n = 92, $p$ = .293) and visual-spatial relationships ($rs$ = .13, n = 92, $p$ = .202).

At a secondary level of analysis, Spearman's rank-order correlation matrix was conducted separately for each education level, but results were inconsistent and non-significant, as depicted in Figure 4b &c.

Concerning letter reversals from children in nursery, all correlations were non-significant after adjusting the significance threshold. Mirrored letters showed a moderate positive correlation with visual discrimination ($rs$ = .33, n = 32, $p$ = .067) and negligible and positive correlation with visual memory ($rs$ = .04, n = 32, $p$ = .810). No correlation was found between mirrored letters with visual-spatial relationships ($rs$ = .00, n = 32, $p$ = .981). For Year 1, mirrored letters yielded a negligible positive correlation with visual discrimination ($rs$ = .10, n = 60, $p$ = .435), and a weak positive correlation with visual memory ($rs$ = .20, n = 60, $p$ = .133) and visual-spatial relationships ($rs$ = .28, n = 60, $p$ = .032).

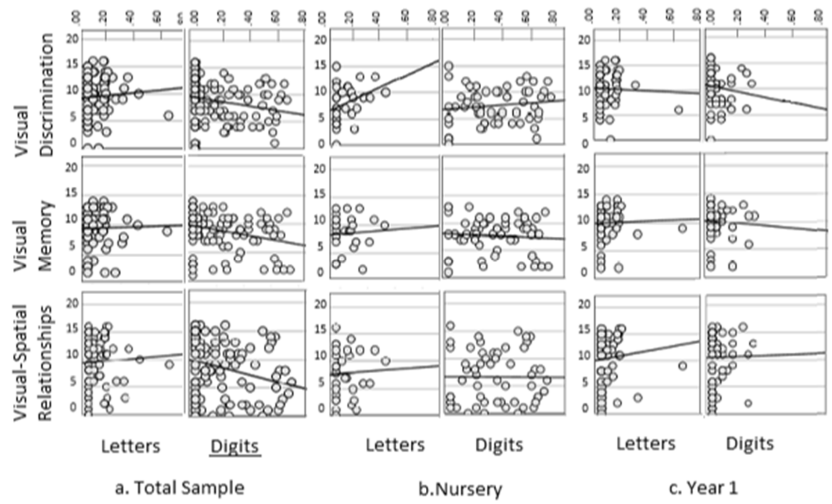


*Figure 4:* Scatterplots of the Correlations between Raw Scores in Visual-Perceptual Skills and the Proportions of Mirrored Letters and Digits

*Note*. The above scatterplots show the correlations between raw scores in visual discrimination, visual memory, and visual-spatial relationship skills with the proportion of mirrored letters and digits as performed by a. the total sample, b. children in nurseries, c. children in year 1. The only significant correlations were between the proportion of mirrored digits and the raw scores of the visual-perceptual skills (as underlined). These correlations were negative, indicating that higher scores in visual-perceptual skills were associated with fewer mirrored digits. There is also a notable floor effect on letter reversals, as most of them are clustered around zero.

Regarding digit reversals from children in nursery, again, all correlations were non-significant after Bonferroni correction. Mirrored digits showed a negligible positive correlation with visual discrimination ($rs$ = .12, n = 55, $p$ = .389) while with visual memory ($rs$ = -.04, n = 55, $p$ = .797) and visual-spatial relationships ($rs$ =-.01, n=55, $p$=.941), correlations were negligible but negative. For Year 1, there were weak negative correlations between digits reversals and visual discrimination ($rs$ = -.26, n = 60, $p$ = .047) while with visual memory ($rs$ = -.03, n = 60, $p$ = .813) and visual-spatial relationships ($rs$ = -.08, n = 60, $p$ = .546) the correlations were negligible and negative.

Overall, significant negative correlations were found only between the raw scores of visual discrimination, visual memory, and visual-spatial relationships subtests and the proportions of digit reversals in the total sample. This suggests that higher scores in visual-perceptual skills were associated with fewer mirrored digits, while all other correlations lacked statistical significance. This implies insufficient evidence to confirm a connection between the remaining variables. Even in cases where a relationship seems apparent, such as the positive correlation between mirrored letters and visual-spatial skills in the total sample—indicating that higher visual-perceptual skills are associated with more letter reversals—this association may be due to random chance rather than a genuine correlation and may not be valid across the broader population.

### 3.2 Effect of Character Orientation on the Number of Reversals

Because a two-way ANOVA was run to assess the effects of the orientation of characters on the reversals of letters and digits (regardless of the education level), four different groups were formed. Their means and standard deviations are presented in Table 3.

*Table 3.* Descriptives Statistics of the Effect of Orientation on Character Reversals

| | N | Mean (SD) |
|---|---|---|
| Right-facing Mirrored Letters | 77 | .03 (.10) |
| Left-facing Mirrored Letters | 77 | .39 (.47) |
| Right-facing Mirrored Digits | 77 | .11 (.22) |
| Left-facing Mirrored Digits | 77 | .15 (.26) |

*Note*. This table shows the means and the standard deviations for the proportions of the reversed right-facing and left-facing letters and digits as performed by all children included in the total sample.

Results indicate a large significant main effect of orientation $F(1,76) = 34.09$, $p < .001$, partial $\eta^2 = .31$ on reversals, with the left-facing characters being reversed the most. The effect of type of characters (letter or digits) on reversals was moderate and significant $F(1,76) = 6.58$, $p = .012$ partial $\eta^2 = .08$. Moreover, there was a large significant interaction effect between the orientation and the type of characters $F(1,76) = 30.45$, $p < .001$, partial $\eta^2 = .29$. This indicates that the orientation of characters had a different effect on children's reversals depending on which type of characters they had written. Looking at the interaction graph in Figure 5, these effects reflect that children generally perform more reversals in both left-oriented digits and letters. Furthermore, when they write left-facing characters, they produce more mirrored letters, while when they write right-facing characters, they perform more digit reversals.

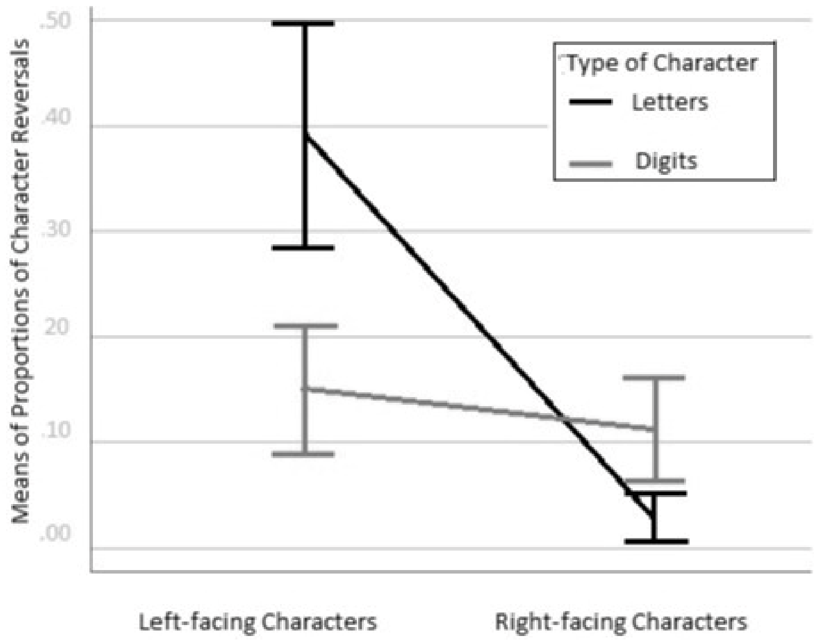


*Figure 5:* Interaction between orientation and type of mirrored characters

*Note*. This line graph depicts the interaction between the orientation of characters and the type of characters. The means of the proportions of the mirrored left-facing and right-facing letters and digits are shown here. Error bars represent the standard errors.

### 3.3 Effect of Education Level on the Number of Reversals

Descriptives of the groups formed after the statistical analysis are shown in Table 4**.** Box's M test showed a significant result (*Box's M* = 55.00, $F(3,108882.74) = 17.83$, $p < .001$), indicating violation of equality of covariance matrices. For this reason, Pillai's trace tool was used, which yielded a large, significant combined effect of education level on the proportions of mirrored letters and digits $V = 0.36$, $F(1, 90) = 51.60$, $p < .001$, partial $\eta^2 = .36$. Moreover, Levene's test showed that variances across the groups of education level for the proportion of mirrored letters were approximately equal ($F(1,90) = 1.92$, $p = .170$), whereas for proportion of mirrored digits were not ($F(1,90) = 60.55$, $p < .001$), showing a violation of homogeneity of variances across those groups.

*Table 4.* Descriptive Statistics of the Proportions of Character Reversals as Performed by Children in Nurseries and in Primary Schools

| | Children in Nursery | | Children in Primary | |
|---|---|---|---|---|
| | N | Mean (SD) | N | Mean (SD) |
| Proportions of: | | | | |
| Mirrored Letters | 32 | .07 (.10) | 60 | .05 (.09) |
| Mirrored Digits | 55 | .34 (.22) | 60 | .04 (.07) |

*Note.* This table presents the means and the standard deviations for the proportions of mirrored letters and digits as demonstrated by children in nurseries or year 1.

For this reason, two different univariate t-tests were conducted to examine the significance of each repeated measure separately. The first t-test examined the effect of the educational level on the proportion of mirrored letters assuming equal variances, while the other focused on the proportion of mirrored digits when equal variances were not assumed, as indicated by Levene's tests. T-test for the proportion of mirrored letters suggested that there was a small but non-significant effect of the educational level on the proportion of mirrored letters, t(90) = .86, $p = .391$, $d = .09$. Moreover, the children from nurseries made slightly more letter reversals (N = 55, M = .07, SD = .09) than children from year 1 (N = 60, M = .05, SD = .09). Additionally, t-test for the proportion of mirrored digits showed a small and significant effect of the educational level on the proportion of mirrored digits, t(64.74) = 9.10, $p < .001$, $d = .16$. The nursery children made more digits-reversals (N = 55, M = .33, SD = .22) than the primary school children (N = 60, M = .04, SD = .07). Figure 6 displays the means of the proportions of left-facing and right-facing reversed letters and digits.

## 4. Discussion

This study aimed to investigate the phenomenon of mirror-writing in typically developing children within the Greek school environment. The initial hypothesis was that the occurrence of mirrored characters would be negatively correlated with visual-perceptual skills. Furthermore, it was anticipated that left-oriented symbols would be reversed more and that children from primary schools would perform fewer reversals than children from nurseries. Results revealed significant negative correlations only between digit reversals and visual-perceptual skills and only in the total sample. Additionally, left-oriented symbols were reversed the most. Moreover, children in primary schools performed significantly fewer digit reversals than children in nurseries. However, this reduction for letter reversals was non-significant.

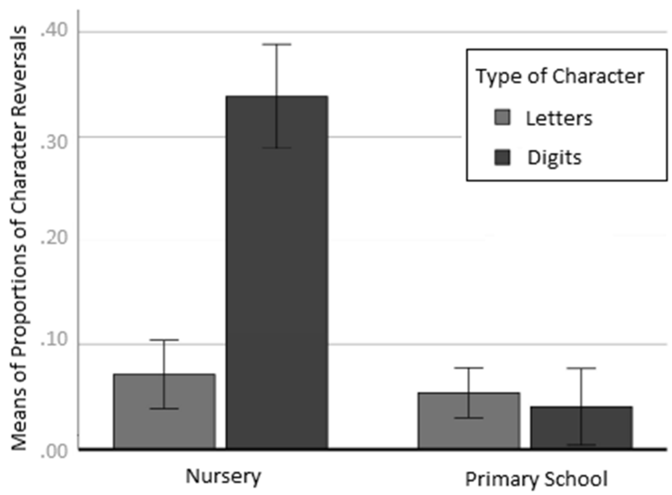


*Figure 6:* Proportions of Mirrored Characters Organized by the Education Level

*Note*. This bar chart presents the means of proportions of the reversed letters and digits as performed by children in nursery and year 1. Error bars show standard errors.

## 4.1 Association of Visual-Perceptual Skills with Mirror-Writing

In the total sample, visual discrimination, visual memory, and visual-spatial relationships were weakly or moderately significantly negatively correlated with digit reversals. However, correlations between visual-perceptual skills and letter reversals were inconsistent and non-significant.

This might have happened because children in nurseries, in the pre-test phase, displayed a good understanding of digits, but exhibited limited recognition of letters, as evidenced by the exclusion of a considerable number of children from the letter analysis. However, the researcher observed that children primarily recognized letters present in their own names, indicating a high level of familiarity likely due to frequent writing practice. Indeed, children in Greek nurseries are frequently asked to copy and write their own names (Ministry of Education and Religious Affairs, Institute of Educational Policy, 2014). This increased familiarity with specific letters could potentially serve as a confounding variable in the analysis. As a result, letter reversals by children in nurseries probably became a less reliable variable. This possibly explains the lack of a significant association between letter reversals and visual-spatial skills in the entire sample, in the following ways: Firstly, because children in nurseries were very familiar with the letters found in their names as they were required to copy and write them many times daily. Consequently, their familiarity with these letters might have improved their ability to remember the orientation of those specific letters, even if their visual-perceptual skills were not as developed. This limited letter knowledge could also be the reason for the floor effect of letters observed in Figure 3. Children recognized and produced very few letters, and therefore, they exhibited a limited number of letter reversals. Another possible explanation could be that children with advanced visual-perceptual skills, such as visual memory, could be capable of recalling more non-familiar letters compared to their peers. This could lead to an increased attempt to write non-familiar letters, resulting in more reversals. However, this remains an untested assumption, and further research should investigate it thoroughly. All the above could explain why letter reversals by children in nurseries introduced variability to the results.

Additionally, the researcher conducted separate correlational analyses of the relationship between the visual-perceptual skills and the amount of letter and digit reversals for each education level. However, results were non-significant in both samples for both letters and digits. This probably happened because of the small number of participants in each group, leading to reduced statistical power. As a result, even if an effect was present, this study was not able to detect it.

These observations suggest that children aged 4–7 years with higher visual discrimination, visual memory, and visual-spatial relationships skills tend to perform fewer digit reversals. This could possibly apply to letter reversals too, but as mentioned, the present study was not able to thoroughly investigate this assumption. These results build on previous findings from other studies that have used different methodological designs to gain insights into children's visual-perceptual abilities and character reversals. For instance, Gregory et al. (2011) suggested that object reversals may be linked to children's visual-spatial relationships skills and/or visual memory, which is supported by findings in this study. Furthermore, Fischer and Tazouti (2012) stated that children aged 5–6 who mirror-write often make orientation errors, especially when relying on memory. Additionally, McIntosh et al. (2018) noted orientation recognition challenges in children exhibiting reversals within the same age range. Considering their methodology, as described in the introduction, their results could have also indicated a potential connection between less-developed visual memory skills and reversals. The findings suggest that character reversals are linked to visual-spatial relationships and visual memory skills. Therefore, it can be hypothesized that typically developing preschool children with stronger visual-spatial or visual memory skills will make fewer character reversals. This assumption aligns with the findings of the current study.

None of the studies discussed above measured visual-perceptual skills. Regarding digits, our results are in accordance with the assumption made above and they indicate that children with greater ability to find the same object as a template among others with different properties (visual discrimination) or orientations (visual-spatial relationships) or with better ability to visually recall symbols (visual memory) tend to make fewer digit reversals. If future studies confirm the correlation found in the current study, it may suggest that typically developing children who frequently exhibit digit reversals could benefit from games targeting visual-perceptual skills, such as visual-memory games, facilitating quicker acquisition of correct digit orientations. However, it is important to specify that this discussion centers on the phenomenon of mirror-writing in typically developing preschool-aged children, who commonly demonstrate character reversals as a typical stage in their writing development. This distinction is crucial as it differentiates mirror-writing in typically developing children from that observed in populations with learning difficulties. While both groups may exhibit character reversals, the implications drawn from this study may not be applicable to the latter group, given the unique challenges they face in the learning process.

### 4.2 Left-Oriented Symbols are Reversed the Most

Results suggest that left-facing letters and digits were significantly more reversed than the right-facing. It was found that left-facing Greek letters were reversed at a rate of 39%, while right-facing only at 3%. Left-facing Arabic digits were reversed at 15%, and right-facing at 11%. These results were similar to Fischer and Koch's (2016) study of 5–6-year-olds, which reported that left-facing characters were used in 39.55% of the cases, and right-facing in 9.17%, decreasing to 11.83% and 5.6% one year later, respectively. Similarly, McIntosh et al. (2018), stated that left-facing Latin letters (Z, J) were most frequently mirrored, at rates of 33% and 26%, respectively. In accordance with these findings, the results from the present study showed that the only left-facing Greek letter (Z) was most frequently reversed, in almost 50% of the attempts from children in nursery and 35% from children in year 1. All the other letters were mirrored at less than 10% of the attempts for both education levels, as presented in Figure 1. Overall, those results confirmed the hypothesis that left-facing symbols, including Greek letters, are significantly reversed the most.

### 4.3 Children in Nurseries Perform More Character Reversals

Lastly, children in Greek nurseries reversed 7% of the letters and 33% of the digits, while children in year 1 5% and 4%, respectively. However, this reduction was significant only for digits and therefore our findings were slightly different than expected. Goebel et al. (2019) observed that in British schools, children in Year 1 exhibited significantly fewer letter and digit reversals compared to children in reception, as described in section 1.4. Those results are in line with their findings only regarding digits, as the results for letters were non-significant and the reduction of the letter reversals was small. This can be explained, as it was found that children in Greek nurseries knew very few letters. Consequently, children in Greek nurseries produced limited number of letters, thus resulting in fewer letter reversals than in British nurseries where children were attempting writing more letters. Therefore, since children in nursery did not perform many letter reversals, the reduction was small and non-significant.

Our findings indicate that by the end of the academic year 1, in Greek primary schools, digit reversals have sharply decreased. This implies that teachers should anticipate digit reversals from children in nurseries but should expect very few digit mirrorings by the end of year 1. Therefore, if they notice that a child consistently makes numerous digit reversals during this time, it could possibly indicate a deviation from typical development.

### 4.4 Strengths

One key strength of this research is its original contribution to the field as it is the first study to investigate the phenomenon of mirror-writing in Greek letters, and Arabic digits within the Greek Schools. This study not only adds an original contribution to the field but also uncovers valuable insights that can guide future research. An additional standout aspect was the innovative methodological approach, setting this study apart from prior research. By employing a standardized assessment tool, the correlation between mirror-writing and visual-perceptual skills was thoroughly examined, ensuring that the data collected accurately reflect the skills being investigated. Finally, this study not only contributes theoretically by enhancing the understanding of the phenomenon but also offers real-world practical insights and presents valuable applications in educational settings.

### 4.5 Limitations

Despite the aforementioned strengths, this study presents some limitations that warrant consideration. First, a convenience sample from schools located in the city center of Heraklion was used. Although schools were from different socioeconomic backgrounds, participants did not constitute a random sample. Also, the number of children from nurseries that were finally included in the letter analysis was unexpectedly small, as few could recognize more than two letters. Consequently, this sample might not fully represent the general population, and further research should address this limitation.

The study's second limitation is the lack of control for factors like the frequency of character production and character knowledge in the sample, which could have influenced the findings. For instance, participants' familiarity with letters in their own names from frequent writing practice might have led them to provide correct orientations based on practice rather than visual-perceptual ability, potentially confounding the results.

The third limitation of the study was unexpected and linked to the unreliability of the variable concerning letter reversals in children from nurseries. The researcher noticed after collecting data that nursery-aged children could only identify a very small number of letters, usually those found in their names. This meant that if a different group of children had been included in the study, they would have written different letters, resulting in different patterns of reversals. Additionally, contrary to the author's initial hypothesis, children with higher visual-perceptual skills did not exhibit fewer letter reversals, potentially due to the unreliable nature of the variable. One potential explanation for this could be that children with advanced visual-perceptual skills may have been able to remember more unfamiliar letters when prompted to write them, potentially leading to making more orientation guesses and therefore more reversals. These factors introduced variability in the results, particularly concerning letter reversals, and impacted the generalizability of the findings to a broader population of children.

### 4.6 Suggestions for Future Research

To address those limitations, further research should be conducted, prioritizing controlling for confounding factors such as letter familiarity and letter frequency. Doing so will ensure that the observed patterns in mirror-writing behavior are accurately attributed to the underlying cognitive processes being studied rather than external influences.

Moreover, informed by both the methodological limitations and results of the present study, future research should take place in the middle of the academic year, aiming for a larger sample size, ideally from year 1. If the study focuses exclusively on year 1 students, who generally have sufficient letter knowledge, omitting the pre-test phase should also be considered. Following these guidelines, further research could investigate whether the correlations between visual abilities and digit reversals also apply to letter reversals, and whether strong visual abilities are more crucial for accurate digit writing than for letters, given that digits have less orientation variability and may require more precise visual skills, while letters allow for more estimation.

Lastly, investigating lowercase letters in the future should be considered due to their greater variability in left-right orientation. This exploration could reveal interesting correlations with visual abilities and provide deeper insights into the relationship between visual-perceptual skills and character reversals.

## 5. Conclusion

To the best of our knowledge, this is the first study to explore mirror-writing in typically developing children within the Greek school environment and to measure visual-perceptual skills and their correlation with character reversals. Consequently, further research is needed to build on these findings. Findings of this study indicate that children with greater visual discrimination, visual memory, and visual-spatial relationships skills tend to perform fewer digit reversals. However, due to specific limitations, extensively discussed, the researcher could not examine whether a similar association existed for letter reversals. Additionally, from the characters being written, results showed that left-oriented symbols are mirrored significantly more than the right-oriented. This finding aligns with previous studies examining the Latin alphabet. Last finding was that by the end of year 1, children perform significantly fewer digit reversals. Letter reversals also decreased but non-significantly, possibly because of the limited knowledge of letters from children in nurseries.

Overall, this study's findings indicate that while theories about mirror-writing remain inconclusive, exploring visual-perceptual skills further is crucial. These results provide valuable insights into this complex phenomenon. Understanding the cognitive processes underlying mirror-writing is essential for gaining deeper insights into writing development and improving educational strategies. Moreover, promoting a comprehensive approach that acknowledges the diverse resources available to children could enrich future research in this field. Methodological limitations that emerged should lay the foundation for future research. By addressing those limitations and conducting targeted studies, we can gain deep insights into character reversals and their underlying factors, contributing to the broader understanding of this area.

## Author Note

There are no conflicts of interest related to this research. No financial support was received for the research, authorship, and/or publication of this article.

Due to ethical considerations, raw data cannot be shared, as participants were informed prior to consent that their data would be accessible only to the research team. Data analysis was conducted using IBM SPSS Statistics (IBM Corp, 2020), and the analysis code is not publicly available. Research materials are available upon request by contacting the author at EKanitaki@qmu.ac.uk. This study was not pre-registered. The author takes full responsibility for the study's design, data collection, analysis, interpretation of the results, and manuscript preparation.

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### Note

1. The standardization of this test took place in 38 states of the USA, on approximately 2000 children. Regarding the psychometric properties, as stated in the manual (Martin, 2006), reliability has been measured using Cronbach's alpha and was for Visual Discrimination = .81, for Visual Memory = .80 and for Visuospatial Relationships = .85 indicating good internal consistency for all the subtests. Additionally, the validity of the test has been assessed and confirmed in terms of content validity, criterion-related validity, and construct validity.

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