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Writing and Drawing with Both Hands as Indicators of Hemispheric Dominance

Irena Labak[1], Darija Šnajder[2], Mirna Kostović Srzentić[3], Mirta Benšić[4], Marina Ništ[5], Vesna Ilakovac[6] and Marija Heffer[7]

[1] »J. J. Strossmayer« University, Department of Biology, Osijek, Croatia
[2] »J. J. Strossmayer« University, School of Medicine, Department of Anatomy, Osijek, Croatia
[3] University of Applied Health Studies, Zagreb, Croatia
[4] »J. J. Strossmayer« University, Department of Mathematics, Osijek, Croatia
[5] Education and Teacher Training Agency, Osijek, Croatia
[6] »J. J. Strossmayer« University, School of Medicine, Department of Biophysics, Medical Statistics and Medical Informatics, Osijek, Croatia
[7] »J. J. Strossmayer« University, School of Medicine, Department of Medical Biology, Osijek, Croatia

A B S T R A C T

Brain lateralization is a common term used to describe dominance of one brain hemisphere over another for a specific function. The right hand dominance in writing, controlled by the left hemisphere, is preceded by development of communicative gesticulation and followed by development of speech in the same hemisphere[1]. We assumed that some people are not aware of their own capability of using the other hand for tasks involving fine motor sequential movements. To prove this hypothesis, the participants were asked to perform one trained task (writing) and one less-trained task (drawing) with a dominant and a non-dominant hand. The final sample was comprised of 1189 children from 14 elementary schools and 8 high schools in the Osijek area, of which 685 elementary school children were attending 1st to 4th grade and 504 high school children were attending 3rd and 4th grade. The participants were asked to write two words, draw a specific object (a vase with flowers) and fill out a questionnaire with 10 questions concerning the classification of handedness and cerebral hemisphere dominance. The self-reported cerebral lateralization assessed in the questionnaire was compared with the drawing and the writing performance. The self-reported and objectively measured hand dominance deviated in the cases of the ambidextrous who consider themselves right-handers. Given the fact that the number of ambidextrous persons was greater in elementary schools than in high schools, we concluded how training of the right hand decreases the ability of using both hands equally for either of the tested functions – writing and drawing.

Key words: *handedness, writing, drawing, lateralization*

Introduction

The human brain functions are more or less asymmetrically distributed between the two hemispheres[2]. One of the best examples is handedness – the right hand, which is more skilled in right-handers, is controlled by the left hemisphere in 90% of human population[3,4]. In general, lateralization is highest for fine motor sequential movements like writing, drawing and vocalization[5,6] or sensory acuity like auditory perception[7].

The lateralized motor behavior starts between 9th and 10th week of gestation with the movements of one arm[8] and reaches its peak between 15th and 18th week of gestation[9]. Besides being genetically predisposed[10], final determination of functional asymmetry depends on a variety of impacts, as it was studied in monozygotic twins with opposite handedness[11–13]. The following issues are still disputable: how and when certain lateralization originated[14]; which functions are coupled and predisposed for the same cerebral dominance[1,15–18]; what is a critical period for initiation, development and maturation[19,20]; a spectrum of epigenetic influences[21–23]; is there

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any benefit of certain asymmetry[24]; what are the signs of pathological outcome[25,26] and how big is the potential for regeneration[27–29] and a shift to another hemisphere[30].

Writing and drawing are complex fine motor functions that involve visual and sensory perception, motor control and a variety of cognitive processes demanding prolonged training and extensive reinforcement during lifetime[31]. It was found that even mix-handed or ambidextrous individuals prefer one hand over the other for writing and drawing[32], which is a sign of functional asymmetry of brain hemispheres regardless of any anatomical substrate[33]. This particular lateralization, based on the skill developed exclusively by training, is easy to access and follow, and consequently it is a good tool used to understand cerebral assignment and maturation. The acquisition of skilled movements, like writing and drawing, induces specific changes in neurons and synapses of the motor area. This phenomenon was studied particularly after injury and surgical interventions in adult patients[34,35]. We expected that the result of permanent rewiring induced by training would have higher asymmetry in the performance of the dominant and the non-dominant hand. Accordingly, we are familiar with cross-cultural studies which have shown lower laterality effects in primitive cultures unfamiliar with a pencil[36].

One of the right shift theory[37] assumptions claims that the ability to use both hands with a genetically determinate bias for one or the other side is a starting point in acquiring any manual skill. Our hypothesis was that a certain amount of training diminishes awareness of the other hand's functionality, particularly in mix-handed or ambidextrous persons, obscuring the original genetic potential for lateralization. The aim of the study was to determine a difference in self-reported and practically demonstrated handedness between younger and older participants.

Participants and Methods

The research was conducted in a population of elementary and high school children from the city of Osijek (and the surrounding area), in Croatia. Out of 1280 tested participants we excluded 35 participants due to incomplete data and 56 participants (53 elementary school children and 3 high school children) based on differently positioned left and right drawings made in the second part of the test[38]. If one of the two drawings was shifted from the central position on the paper, it was considered as a possible sign of one-sided cerebral lesion. The final sample was comprised of 685 children from 14 elementary schools and 504 children from 8 high schools, 1189 children in total. We limited our target groups to early elementary school children (1st to 4th grade) as they have just developed their ability to write and to children of the last two grades of high school who had a prolonged period of handwriting training.

A two part leaflet was used in the research. The first part was a questionnaire, based on the previous studies[32,39], with 10 Likert-style questions for the subjective assessment of commonness of using the right hand or leg for various actions (ball throwing, ball kicking, teeth brushing, hair combing, door opening, erasing, cutting with the scissors, cutting with a knife, writing, foot tapping to the rhythm). We consider this part subjective because the answers to each question relied on the memory as an alternative to being physically tested. Instead of using eight categories of hand preference[32], we classified our participants into three categories only: 'consistent right', 'consistent left' and 'inconsistent' mixed or ambidextrous[40], based on statistical justification.

The offered answers were: never (scored with –2 points), sometimes (scored with –1 point), mostly (scored with 1 point) and always (scored with 2 points). The children with the average score higher than or equal to 0.5 were considered to be right handed, those whose average score lay between –0.5 and 0.5 were considered ambidextrous, and children with average score less than or equal to –0.5 were considered to be left handed. Out of 10 questions we finally rated 7: three questions from the Annett Hand Preference Questionnaire (AHPQ) and previously classified as 'primary' actions[32] (writing, throwing with a hand, teeth brushing), one 'non-primary' question from

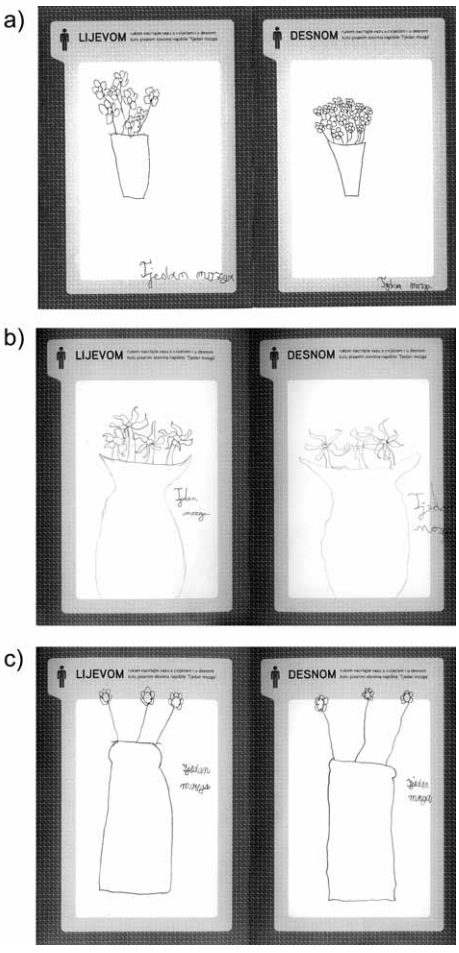

Fig. 1. An example of a drawing/written text made by a right-hander, a left-hander and an ambidextrous.

the same inventory (scissors), one question from the Edinburgh Handedness Inventory (EHI)[39] which is different between two inventories (knife) and two questions about foot preference (ball kicking and beating to the rhythm) related to whole-body finely sequenced movements[41].

In the second part of the leaflet children were supposed to draw a vase with flowers and write the text »Tjedan mozga« (»The Brain Awareness Week«) with both, the right and the left hand (Figure 1). They were instructed to do those activities using their right hand first and then their left hand. The relative size and determination of both the drawing and the text, made with the left and the right hand, were assessed and scored. Two independent judges, not aware of the research hypothesis, measured the width and the height of the text and the drawing (in cm) made with the left and the right hand and the corresponding area was calculated. The size was scored 0, if the area ratio between the drawing and the text made with the right and the left hand did not exceed 20%. When the drawing/the text made with the right hand was more than 20% smaller – the score was 1 and if the drawing/the text made with the left hand was more than 20% smaller – the size was scored –1. The scoring was based on the finding from the kinematics analysis of drawing movements: the drawing made with the non-dominant hand is larger than the drawing made with the dominant hand[42]. Determination was also independently scored by two judges. The assumption was that accuracy is a good predictor of handedness[43]. If there was no difference in determination of the drawings/the texts made by the right and by the left hand, the determination was scored 0. When the right-hand made drawing/ text was more determined – the score was 1 and if the left-hand made drawing/text was more determined – the score was –1. Inter-rater agreement in determination scoring was very good for both the text and the drawing (κ=0.92 for the text and κ=0.93 for the drawing, $p< 0.001$ for both). The weighted average of scores was used as a basic criterion for objective determination of hand domination. Weight of 1 was assigned to the size of the text score, 3 to text determination score, 5 to the size of the drawing score and weight of 7 was assigned to the drawing determination score. Weighting was based on the assumption that writing is a more practiced skill than drawing.

Statistical methods

The data are presented as absolute and relative frequencies. Rater agreement was assessed using an inter-rater agreement statistic κ. The difference between the two handedness preference classifications was tested with the Bowker's symmetry test. The difference in distributions of hand preference between elementary and high school children was tested with a χ^2-test. All p-values were two tailed. The confidence intervals (CI) were estimated at the 95% level and calculated using the statistical package Confidence Interval Analysis (CIA) (version 2.0.0, Trevor Bryant, University of Southampton, UK). The analyses were conducted with the use of SAS software (version 8.2, Cary, NC, USA), with the significance level set at $p<0.05$.

Results and Discussion

Out of 1189 examinees, there were 807 (67.9 %) right handed, 61 (5.1%) left handed and 321 (27.0%) ambidextrous children (based on the drawing and the text assessment). There was no distinction in hand domination distribution between the groups of primary and high school children (χ^2=1.16, df=2, p=0.560) (Table 1).

According to the subjective hand domination assessment, there were 1017 (85.5%) right handed, 68 (5.7%) left handed and 104 (8.7%) ambidextrous children. There

TABLE 1
DISTRIBUTION OF HAND DOMINATION IN GROUPS OF ELEMENTARY AND HIGH SCHOOL CHILDREN BASED ON DRAWING/WRITING TEST

Hand domination	Number (%) of children		Difference in proportion	95% CI boundaries	
	Elementary school	High school		Lower	Upper
Right-handers	458 (66.9)	349 (69.2)	–2.4	–7.7	3.0
Ambidextrous	193 (28.2)	128 (25.4)	2.8	–2.4	7.8
Left-handers	34 (5.0)	27 (5.4)	–0.4	–3.1	2.1

TABLE 2
DISTRIBUTION OF HAND DOMINATION IN GROUPS OF ELEMENTARY AND HIGH SCHOOL CHILDREN BASED ON SUBJECTIVE ASSESSMENT

Hand domination	Number (%) of children		Difference in proportion	95% CI boundaries	
	Elementary school	High school		Lower	Upper
Right-handers	565 (82.5)	452 (89.7)	–7.2	–11.0	–3.2
Ambidextrous	81 (11.8)	23 (4.6)	7.3	4.2	10.3
Left-handers	39 (5.7)	29 (5.8)	–0.1	–2.9	2.6

was a significant distinction in hand domination distribution between the groups of elementary and high school children (χ^2=19.27, df=2, p<0.001) (Table 2). The proportion of ambidextrous children was higher in the group of elementary school children than in the high school children. We found no gender differences in the distribution of hand preference in either subjective or objective assessment in both ages (data not shown).

The cross classification of subjective and objective hand preference showed a significant lack of symmetry both in elementary (Table 3) and high school (Table 4) children (Bowker's test, p<0.001 for both).

The scoring of size and determination of words and drawing had a different impact on the final outcome of the objective assessment of hand preference (Tables 5 and 6). Determination in word writing matches determination in picture drawing in both elementary (Bowker's test, p=0.184) and high school group (Bowker's test, p=0.368).

If the size of the text or the drawing were used as classification criteria the majority of participants were classified as ambidextrous. The participants from elementary and high school were equally (un)successful in writing the text of the same size on the left and the right side of the leaflet, but were significantly better in high school in making the same size of the drawings with the right and the left hand. The cross classification of handedness determined by the size of the drawing and a full combination of objective criteria reveal that most of the participants that were classified as ambidextrous, according to the size of the drawing, were right handed – if we include all criteria (Tables 7 and 8). Likewise, the percentage of the ambidextrous, according to the size of the drawing, classified as right handed by all objective criteria were significantly higher in high school *versus* elementary school.

The development of motor skills in the dominant and the non-dominant hand preceded for both hands in spite of the fact that just one hand is trained like it was published before[31]. It is known that at performing various shapes two hands are using different groups of muscles and different strategies[44]. The difference in kinematics is much smaller if two hands are producing mirror images[45]. We designed the drawing task with various shapes

TABLE 3
CROSS CLASSIFICATION OF SUBJECTIVE AND OBJECTIVE HAND PREFERENCE IN THE GROUP OF ELEMENTARY SCHOOL CHILDREN

Objective assessment of hand preference	Subjective assessment of hand preference, number (%) of children			Total
	Right-handers	Ambidextrous	Left-handers	
Right-handers	406 (59.3)	44 (6.4)	8 (1.2)	458 (66.9)
Ambidextrous	153 (22.3)	27 (3.9)	13 (1.9)	193 (28.2)
Left-handers	6 (0.9)	10 (1.5)	18 (2.6)	34 (5.0)
Total	565 (82.5)	81 (11.8)	39 (5.7)	685 (100)

TABLE 4
CROSS CLASSIFICATION OF SUBJECTIVE AND OBJECTIVE HAND PREFERENCE IN THE GROUP OF HIGH SCHOOL CHILDREN

Objective assessment of hand preference	Subjective assessment of hand preference, number (%) of children			Total
	Right-handers	Ambidextrous	Left-handers	
Right-handers	335 (66.5)	11 (2.2)	3 (0.6)	349 (69.2)
Ambidextrous	110 (21.8)	7 (1.4)	11 (2.2)	128 (25.4)
Left-handers	7 (1.4)	5 (1.0)	15 (3.0)	27 (5.4)
Total	452 (89.7)	23 (4.6)	29 (5.8)	504 (100)

TABLE 5
DISTRIBUTION OF HAND DOMINATION IN THE GROUP OF ELEMENTARY SCHOOL CHILDREN BASED ON TEXT/DRAWING SIZE AND DETERMINATION

Hand preference	Number (%) of children			
	Size of the text	Size of the drawing	Determination of the text*	Determination of the drawing*
Right-handers	305 (44.5)	235 (34.3)	599 (87.4)	609 (88.9)
Ambidextrous	210 (30.7)	283 (41.3)	35 (5.1)	31 (4.5)
Left-handers	170 (24.8)	167 (24.4)	51 (7.4)	45 (6.6)

* The participants with positive average determination score (ADS) were considered right-handed, those with negative ADS were considered left-handed and the participants whose ADS was 0 were considered ambidextrous

TABLE 6
DISTRIBUTION OF HAND DOMINATION IN THE GROUP OF HIGH SCHOOL CHILDREN BASED ON TEXT/DRAWING SIZE AND DETERMINATION

Hand preference	Number (%) of children			
	Size of the text	Size of the drawing	Determination of the text*	Determination of the drawing*
Right-handers	255 (50.6)	123 (24.4)	458 (90.9)	459 (91.1)
Ambidextrous	168 (33.3)	259 (51.4)	3 (0.6)	2 (0.4)
Left-handers	81 (16.1)	122 (24.2)	43 (8.5)	43 (8.5)

* The participants with positive average determination score (ADS) were considered right-handed, those with negative ADS were considered left-handed and the participants whose ADS was 0 were considered ambidextrous

TABLE 7
CROSS CLASSIFICATION OF HANDENESS DETERMINATED BY THE DRAWING SIZE AND OBJECTIVE HAND PREFERENCE IN THE GROUP OF ELEMENTARY SCHOOL CHILDREN

Objective assessment of hand preference	Hand preference according to the drawing size			Total
	Number (%) of children			
	Right-handers	Ambidextrous	Left-handers	
Right-handers	219 (93.2)	239 (84.5)	0 (0.0)	458 (66.9)
Ambidextrous	16 (6.8)	32 (11.3)	145 (86.8)	193 (28.2)
Left-handers	0 (0.0)	12 (4.2)	22 (13.2)	34 (5.0)
Total	235 (100)	283 (100)	167 (100)	685 (100)

TABLE 8
CROSS CLASSIFICATION OF HANDEDNESS DETERMINATED BY THE DRAWING SIZE AND OBJECTIVE HAND PREFERENCE IN THE GROUP OF HIGH SCHOOL CHILDREN

Objective assessment of hand preference	Hand preference according to the drawing size			Total
	Number (%) of children			
	Right-handers	Ambidextrous	Left-handers	
Right-handers	109 (88.6)	240 (92.7)	0 (0.0)	349 (69.2)
Ambidextrous	14 (11.4)	5 (1.9)	109 (89.3)	128 (25.4)
Left-handers	0 (0.0)	14 (5.4)	13 (10.7)	27 (5.4)
Total	123 (100)	259 (100)	122 (100)	504 (100)

rather than objects which are easy to copy and participants were not warned not to draw images with mirror symmetry. Just 7.6 % of the participants from elementary school and 1.2 % of the participants from high school produced such drawings and neither one produced such writing. We suppose that most of the participants draw and write from the left to the right side using different groups of muscles on two different hands. Likewise, since drawing tasks were complex, the pure motor action was interfered by memory, visual perception and attention.

With increasing age, the performance becomes faster, more accurate and is done with less hesitation[46]. The studies comparing the performance of the dominant and the non-dominant hand found functional asymmetry in the quality of produced movements[43]. The drawing and the writing made with the non-dominant hand, particularly in the case of smaller and more complex tasks, were less precise, with more errors and slower[46]. During development, discrete movements involving proximal musculature of the elbow and the wrist were trained first, while movements of fingers and complex tasks involving several different muscles, like in drawing a small circle, developed last and had highest right-left-difference[31,42].

In our study, the writing task was more demanding than the drawing task because it involved smaller curved shapes. The frame of mind is to write in the size which is common for the space between the lines of a regular school notebook, while drawing was fitted into A5 paper dimensions. We found out that the writing task gave us more information about how well manual precision is trained, whereas the drawing task gave more information about the perception of space.

If we used a combination of criteria to score the objective manual performance, the percentage of right handed participants was 66.9% for elementary school and 69.2% for high school, which was a result close to the one obtained in the study using the classification of just three categories of handedneness[40]. At the same time, using

the questionnaire, we got 82.5% of right handed in elementary school *versus* 89.7% in high school, which were the results obtained in previous studies with similar questions[32,47]. Contrary to the study comparing the hand preference questionnaire and the hand performance measures[48], our results showed a significant discrepancy, particularly in elementary school and came closer to their results in the group of high school participants.

The major difference between the two groups of different age came out in cross classification of subjective and objective hand preference (Tables 3 and 4). In elementary school just 59.3% of all participants were right handed by both criteria, objective and subjective. This number rose to 66.5% in high school participants. The change in percentage was mainly due to shrinkage in group of participants who were classified as ambidextrous by the objective criteria, but consider themselves right handed (11.8 % of participants from elementary school *versus* 4.6 % from high school).

Contrary to the studies finding a gender difference in manual skills[49], we found no difference in either subjective or objective assessment of handedness[46,50]. Determination of writing and drawing were exactly the same in the same age group and improved steadily toward older participants. Both tasks were based on the same manual skill and were equally trained despite the fact that one of them was less frequently performed. A similar phenomenon was already noticed in a group of patients trained to produce fine reaching movements after which they improved in drawing circles, which wasn't an activity they needed to train for that task[51].

The size of drawing was the most intriguing component of all graded components in the objective assessment of handedness. While the size of the text did not change during maturation, which is evident from perfectly identical distribution found in elementary and high school, the size of the drawing changed significantly. We supposed that the production of a drawing is a task which involves practice in visual perception and space orientation, which is gradually achieved during maturation.

The subjective assessment of handedness gives a significantly different result from practical demonstration of the skill. Years of practice make a further right shift in mental awareness. Writing and drawing with both hands are relatively short and easy to perform, providing a consistent distribution of handedness in groups of various ages, working as a promising tool for the objective assessment of cerebral lateralization.

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M. Heffer

»J. J. Strossmayer« University, School of Medicine, Department of Medical Biology, Josipa Huttlera 4, 31000 Osijek, Croatia
e-mail: mheffer@mefos.hr

PISANJE I CRTANJE S OBJE RUKE KAO POKAZATELJI DOMINANTNE HEMISFERE

S A Ž E T A K

Lateralizacija mozga uobičajeni je naziv koji se koristi pri opisivanju dominantnosti jedne hemisfere mozga u odnosu na drugu za određene funkcije. Dominaciji desne ruke u pisanju, kontroliranoj lijevom hemisferom, prethodi razvoj komunikacijske gestikulacije nakon kojega slijedi razvoj govora u istoj hemisferi[1]. Pretpostavljamo da neki ljudi nisu svjesni vlastite sposobnosti korištenja druge ruke u izvršavanju zadataka koji uključuju fine uzastopne motoričke pokrete. Kako bismo potvrdili ovu hipotezu, ispitanike smo zamolili za izvođenje jedne uvježbane zadaće (pisanje) i jedne manje uvježbane zadaće (crtanje) s dominantnom i nedominantnom rukom. Konačni uzorak sastojao se od 1189 učenika iz 14 osnovnih i 8 srednjih škola s područja Osijeka, od kojih je 685 učenika osnovne škole pohađalo 1. do 4. razred, a 504 učenika srednje škole pohađalo je 3. i 4. razred. Ispitanici su zamoljeni da napišu dvije riječi, nacrtaju zadani objekt (vazu s cvijećem) i odgovore na upitnik koji se sastojao od 10 pitanja korištenih pri klasifikaciji dominantnosti ruke odnosno dominantnosti moždane hemisfere. Samo-referirana moždana lateralizacija procijenjena upitnikom uspoređivana je s izvedbom crteža i pismom. Samo-referirana i objektivno izmjerena dominacija ruke odstupale su u slučaju ambidekstera koji sebe smatraju dešnjacima. Na osnovi činjenica da je broj ambidekstera veći u osnovnoj školi nego u srednjoj, zaključujemo da treniranje desne ruke umanjuje sposobnost korištenja obje ruke podjednako za obje testirane funkcije – pisanje i crtanje.