How well can fingers remember？

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1 Introduction

1.1 Our research

Repeatedly writing down things help us remember [1]. Knowing that from the research of previous scholars, we are still curious about how exactly different finger participate in this process. In other words, we have the research question:

Do fingers help in the write-to-remember process? Can they conduct the act of “remembering” by themselves? What can they remember?

In order to investigate in these questions, we decide to hold every finger that is active in writing(thumb, index finger, middle finger) as a pen, and try to recreate a picture that has been generated by computer. The experiment shows that each finger has different task that it is good at or bad at.

1.2 Theoretical background

Compared to typing on a keyboard, handwriting seems to be more effective in promoting learning and memory. This viewpoint appears to be widely accepted, even when using digital pens or handwriting on interactive computer screens. Professor Eva Ose Askvik from NTNU believes that the combination of tactile sensations and these movements creates connections between different parts of the brain, enhancing sensory engagement and thus facilitating better learning and memory outcomes[2]. While gripping the pen, the coordinated operation of the thumb, index finger, and middle finger is essential. Considering the variability in individuals' pen-holding or writing preferences, we are curious to explore whether there are differences in visual memory effects based on the thumb, index finger, middle finger, and their combined pen-gripping actions.

Memory refers to the neural cognitive ability to encode, store, and retrieve information[3]. In comparison to Long-Term Memory(LTM), Working Memory(WM) is characterized by its short-term nature and limited capacity, which is responsible for the ongoing tasks processing. Among these, Visual Working Memory (VWM) is a core cognitive function that enables us to identify the features of objects and perceive their spatial locations at any given moment, aiding in the concentration of attention. Within seconds after a visual image disappears from our line of sight, Visual Working Memory helps us retain it in our minds. George A. Miller found that the Visual Working Memory capacity in adults is limited to approximately four visual items and the capacity for visual items varies little with factors such as color, size, and familiarity[4].

Handwriting is considered a multi-component task, indicating that the act of writing is a complex interplay of various cognitive processes and biophysical phenomena[5]. Importantly, there exists a reciprocal influence between handwriting and visual short-term memory. To begin with, the capacity of visual short-term memory significantly impacts an individual's handwriting performance. The writing process demands the memorization and manipulation of a series of information, and the capacity and stability of visual short-term memory play a crucial role in facilitating this process. Research supports the idea that children struggling with handwriting often exhibit visual memory deficits[6]. Furthermore, it is noteworthy that the hand posture and movements during handwriting can, in turn, affect visual working memory. Research indicates that the involvement of gestures aids participants with lower visual working memory capacity in solving complex problems.[7]

2 Methods & Materials

2.1 Participant

We used the method of self-experimentation, with researcher Huien being the subject of the experiment. Another researcher, Jiaxin Zhang, roled as the observer. The three fingers involved in holding the pen, namely the thumb, index finger, and middle finger, along with the pen itself, constitute four types of gesture stimuli. Each of them was tested three times in separate experiments.

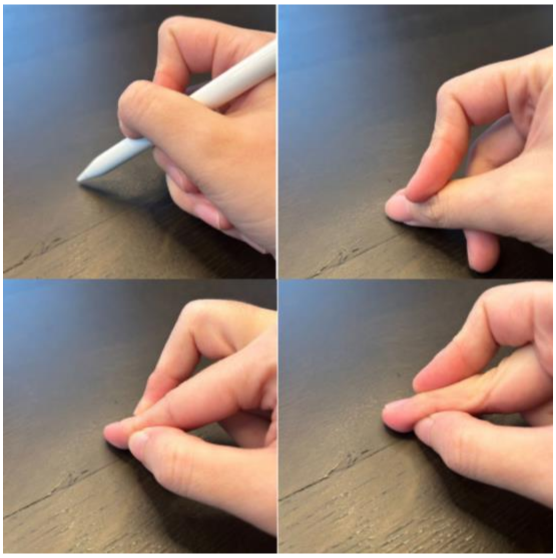


Figure 1. Gripping different tools: pen(upper left), thumb(upper right), index finger(lower left), middle finger(lower right)

2.2 Apparatus and stimuli

Visual stimuli for this experiment were presented on a 13.3-inch MacBook running a Processing program, while the Procreate on a 10.2-inch iPad served as both sketchpad and canvas. After observing images in Processing, the participant replicated and reconstructed them on Procreate using a single-finger gesture. To avoid potential interference from canvas size discrepancies, both the Processing and Procreate canvas settings were standardized at 600x600. The stylus used was the first-generation Apple Pencil, compatible with the iPad.

2.3 Programming Design

To avoid interference of colors in visual memory, the Processing canvas is uniformly set to a 600x600 square with a white background, and elements are outlined in black. The core generating functions are as follows:

drawRandomShape() generates one of four shapes (circle, rectangle, star, trapezoid) with random sizes (20 to 100 pixels) and positions within the canvas boundaries, ensuring no overlap with the edges.

drawRandomLine() creates a line, which could be straight, curved (arc), or complex (Bezier), with endpoints and control points randomly placed within the canvas, offering diverse line orientations and lengths.

drawRandomLetter() randomly selects a letter from A to Z and displays it in a random size (20 to 100 pixels) and position on the canvas, ensuring clear visibility and no edge overlap.

drawStar() constructs a star shape at a specified location with adjustable inner and outer radii, using a calculated angle to evenly distribute points around a full circle.

drawTrapezoid() creates a trapezoid based on a given position and size, ensuring that the shape's vertices are calculated to maintain its trapezoidal form within the specified width and height.

2.4 General Procedure

A random image was generated following the logic of the previous processing program. During the memorization process, the participant was instructed to repeatedly practice the image using a single gesture stimulus on an iPad. After 60 seconds, the image was closed, and participant was required to recreate the image on a new sheet of paper using the same gesture. Accuracy was prioritized over speed in the recreating process. Upon completion of a single experiment, participants reported the memorization process to the observer. The observer then compared the difference of generated picture and handwriting picture, and evaluated the accuracy of different aspects.

Figure 2. Image generated by Processing(left) and image recreated by participant(right)

3 Result

In this part, both objective and subjective results will be discussed. Objective results are based on scoring data, and subjective results are based on observing notes during the experiment. In the end, a job profile of each tool (finger or pen) will be summarized based on both results, as an attempt of delivering a creative output. There, readers will know the skills and drawbacks of each finger in recreating pictures.

3.1 Objective result

After reproducing all pictures, we assess and score each element of all the reproduction works to see how well the reproduction task develops, and compile them in a table (see table 1). In total, 108 lines of scoring data are recorded.

Tool	Element	Absolute Position	Relative Position	Size	Shape
Pen Thumb Index finger Middle finger	Arc Straight line Letter(A-Z) Star Quadrilateral Circle	0(bad) 1(OK) 2(good) or 3(perfect)	0(bad) 1(OK) 2(good) or 3(perfect)	0(bad) 1(OK) 2(good) or 3(perfect)	0(bad) 1(OK) 2(good) or 3(perfect)

Table 1: scoring standard

3.1.1 Tool and element (circle, letter, etc.)

After analyzing the raw scoring data, we found the connection between tools and elements. To explore whether different combinations of tools and elements differ significantly in the distribution of ratings, the chi-square test is chosen to be done because firstly, it fits the feature of our data, and secondly, it looks at differences in the frequency distribution of ratings.

χ^2: 323.88
p-value: 0.00034
Degree of freedom: 242

The p-value of the chi-square test is less than 0.05, indicating there is significant difference. In other words, some tools exhibit significantly different distribution patterns of scores when reproducing elements compared to other tools.

Tool	Best Scoring Element	Best Scoring Element-Average Scoring	Worst Scoring Element	Worst Scoring Element-Average Scoring
Pen	Quadrilateral	3.00	Straight line	2.2
Thumb	Letter	2.67	Straight line	1.5
Index finger	Letter	2.44	Circle	1.5
Middle finger	Straight line	2.86	Circle	2.25

Table 2: Best and Worst Scoring element of each tool

3.1.2 Tool and element features (position, size, etc.)

To investigate how well different tools perform in the aspect of element features (absolute position, relative position, size, shape), we first want to make sure that a significant difference exists. According to the results of the Shapiro-Wilk normality test, the scores for all dimensions did not fit a normal distribution ($p < 0.05$), so we need to use the Kruskal-Wallis H-test instead of ANOVA to determine if there is a significant difference in scores for element features. Below are the results:
Absolute position: the difference between tools was significant (p-value = 0.0074), with the pen and middle finger performing well on this dimension.
Size: significant differences (p-value = 0.0396), with the pen performing best on this dimension.
Relative position: the difference between tools was NOT significant (p-value = 0.1843), but the index finger had a relatively high mean score on this dimension.
Shape: NOT significant (p-value = 0.1523), but the pen scored the highest.

3.2 Subjective result

According to our text records rather than data records, the feature of each tool can be described as follows.

Pen: Memorization strategies appear to be more flexible when using the pen, possibly because the pen is better suited for detailed manipulation; When using the pen to reproduce, the number and type of elements are usually accurate, but there may be some bias in the exact position and orientation of the elements.

Thumbs: Thumbs tend to follow a specific order when memorizing, such as left-to-right or top-to-bottom, which helps to maintain consistency in memory; During reduction, the thumb shows consistency in order, but sometimes makes errors in the position and orientation of elements, such as inaccurate position or orientation of lines and letters.

Index Finger: The index finger is memorized in a variety of ways, from left to right or according to the importance of the element. Memorization seems to focus more on the details of the elements than on the overall layout; When reducing, the index finger shows attention to detail, but sometimes at the expense of relative positional relationships between elements, resulting in deviations from the overall layout.

Middle Finger: The middle finger appears to use a subregional approach when memorizing, such as dividing the image into upper, middle, and lower parts to memorize; When reduced, the performance of the middle finger usually includes elemental accuracy, but sometimes errors in size and position occur, especially in maintaining the correct relative position between elements.

3.3 Creative conclusion: LinkedIn Profile of each tool

Pen – The Precision Engineer
About: Hi network, I'm the Pen! Good at drawing quadrilaterals with an average score of 3.00, I'm your first choice for precise and accurate shapes. While I may struggle a bit with straight lines (average score of 2.2), my overall performance in absolute position (p-value = 0.0074) and size (p-value = 0.0396) is top in the industry, making me ideal for tasks requiring detailed attention and accuracy. My strength lies in bringing clarity and precision to the table.
Skills: Expert in Quadrilaterals; High Precision in Size & Absolute Position; Good for Detailed and Delicate Tasks

Thumb – The Letter Specialist
About: Hello, I'm the Thumb. Specializing in letters with a solid average score of 2.67, I am reliable for tasks involving alphabetic representation. However, straight lines can be a bit challenging for me, with a lower score of 1.5. My ability to handle various shapes may not be perfect, but my proficiency with letters makes me a valuable asset for tasks that involve textual elements.
Skills: Proficient in Letter Recreation; Versatile with Different Elements; Adaptable to Various Tasks

Index Finger – The Relative Position Specialist
About: Greetings network, I'm the Index Finger. While I score well in letters (average 2.44), my expertise really shines in handling relative positions, with a relatively high mean score in this dimension (p-value = 0.1843). I do face some challenges with

circles (average score 1.5), but my overall ability to maintain the integrity of spatial relationships makes me a strong candidate for tasks requiring a holistic view of the layout.
Skills: Strong in Letter Reproduction; Skilled in Maintaining Relative Positions; Holistic Approach to Tasks

Middle Finger – The Straight Line Manager
About: Hi there, I'm the Middle Finger. My strength is in creating straight lines, scoring an impressive 2.86 average. While circles can be a bit tricky (average score 2.25), my performance in absolute position is noteworthy (p-value = 0.0074). I excel in tasks that require a linear and structured approach, making me suitable for designs and patterns that rely heavily on linear elements.
Skills: Expert in Straight Lines; Proficient in Absolute Positioning; Ideal for Linear and Structured Tasks

4 Conclusion

Handwriting is a task that involves the coordination of motion and sensation. During the process of handwriting, visual information is translated into a form that the brain can comprehend and store, thereby being retained in visual working memory for a certain period. This experiment, by comparing the short-term memory effects of images when using different fingers (thumb, index finger, middle finger) and writing with a pen, identifies the distinct roles played by various fingers in image short-term memory.

However, since this experiment employs a self-experimentation approach, factors such as the participant's own handwriting preferences and the uniqueness of visual memory capacity may limit the generalization of the findings. Additionally, despite the utilization of metrics such as absolute and relative positions when scoring the reconstructed images, it remains challenging to entirely eliminate subjective interference.

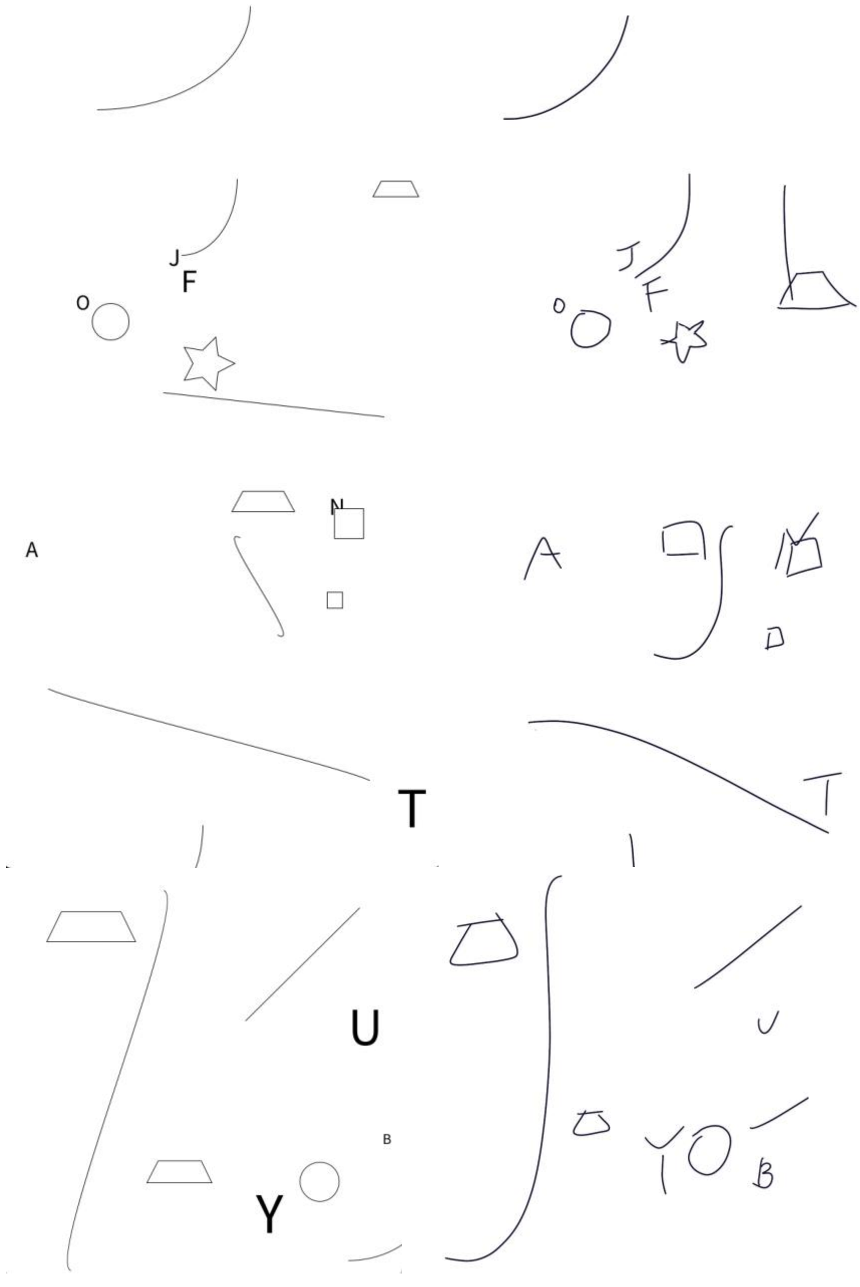
Overall, this study provides a window into understanding the cognitive stimulation by handwriting posture and movements. It has implications for individuals with hand disabilities, such as those lacking fingers or having extra fingers, and also contributes to a more refined design of hand postures in human-computer interaction.

References

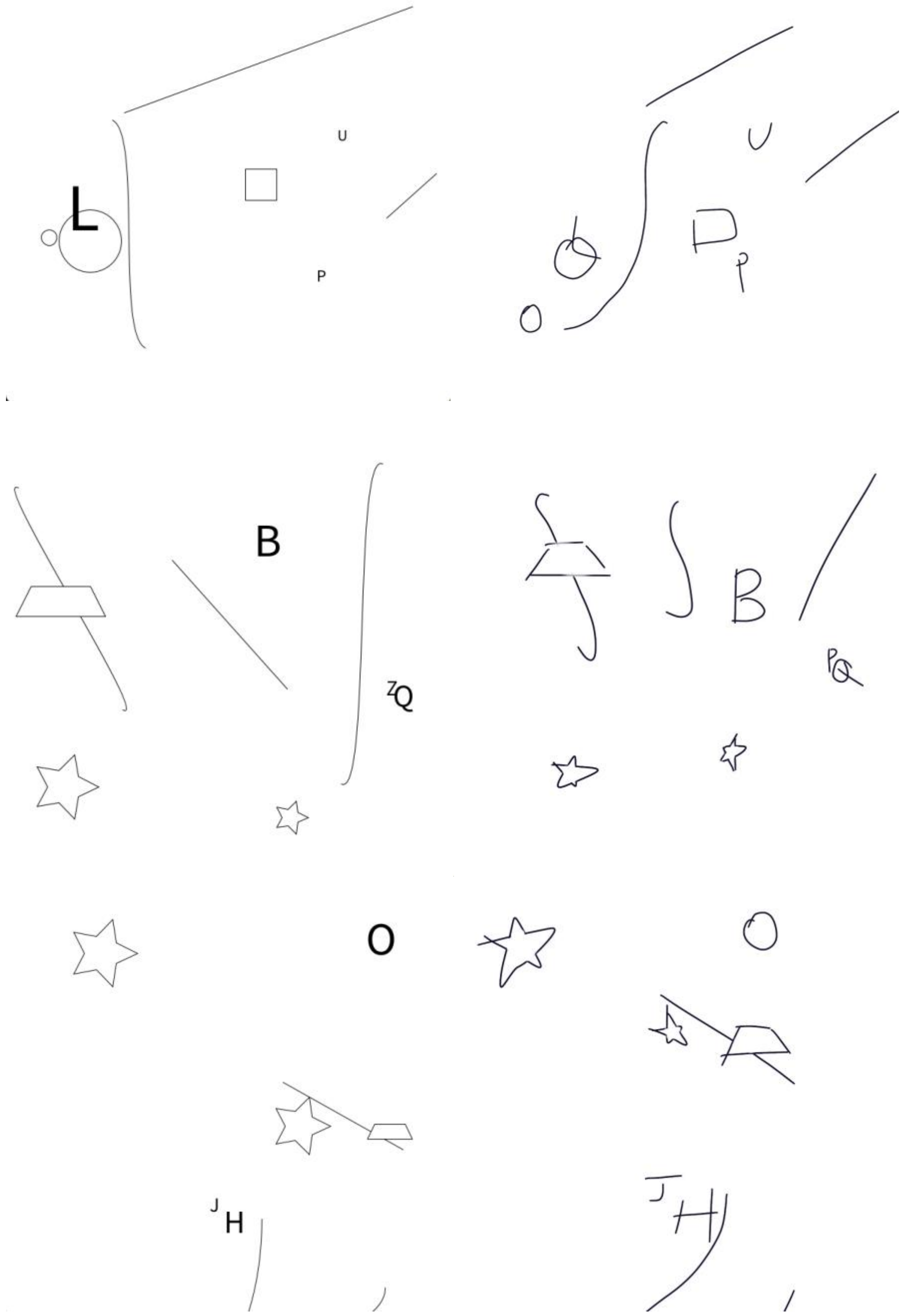
1. Naka, M., & Naoi, H. (1995). The effect of repeated writing on memory. *Memory & cognition*, *23*(2), 201–212. https://doi.org/10.3758/bf03197222
2. Askvik, E. O., Van Der Weel, F., & Van Der Meer, A. (2020). The importance of cursive handwriting over typewriting for learning in the classroom: A High-Density

EEG Study of 12-Year-Old children and Young adults. Frontiers in Psychology, 11. https://doi.org/10.3389/fpsyg.2020.01810
3. Echterhoff, G., & Hirst, W. (2009). Social influence on memory. Social Psychology, 40(3), 106–110. https://doi.org/10.1027/1864-9335.40.3.106
4. Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. Psychological Review, 63(2), 81–97. https://doi.org/10.1037/h0043158
5. Van Galen, G. (1991). Handwriting: Issues for a psychomotor theory. Human Movement Science, 10(2–3), 165–191. https://doi.org/10.1016/0167-9457(91)90003-g
6. Vlachos, F., & Karapetsas, A. (2003). Visual Memory Deficit in Children with Dysgraphia. Perceptual and Motor Skills, 97(3_suppl), 1281–1288. https://doi.org/10.2466/pms.2003.97.3f.1281
7. Eielts, C., Pouw, W., Ouwehand, K., Van Gog, T., Zwaan, R. A., & Paas, F. (2018). Co-thought gesturing supports more complex problem solving in subjects with lower visual working-memory capacity. Psychological Research, 84(2), 502–513. https://doi.org/10.1007/s00426-018-1065-9

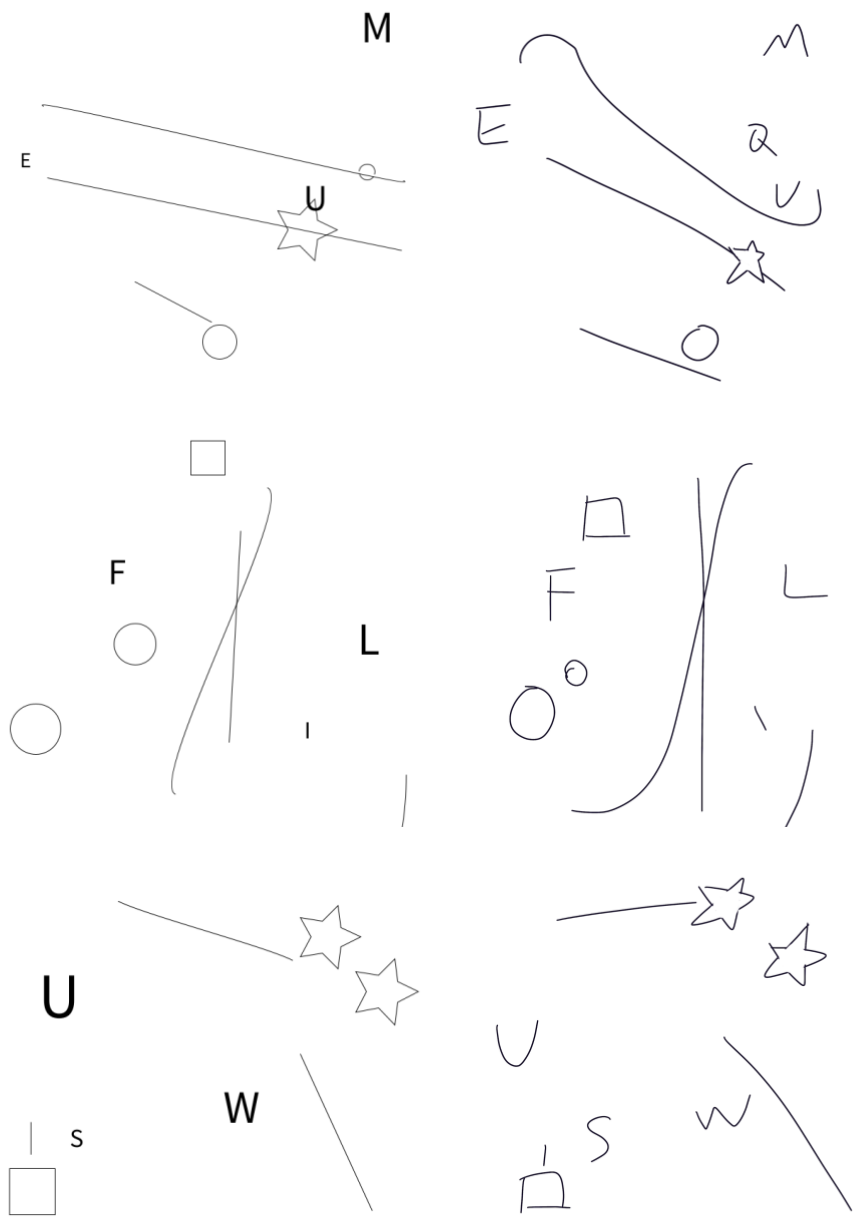
Appendix 1: Images generated by Processing(left) and finger(right)



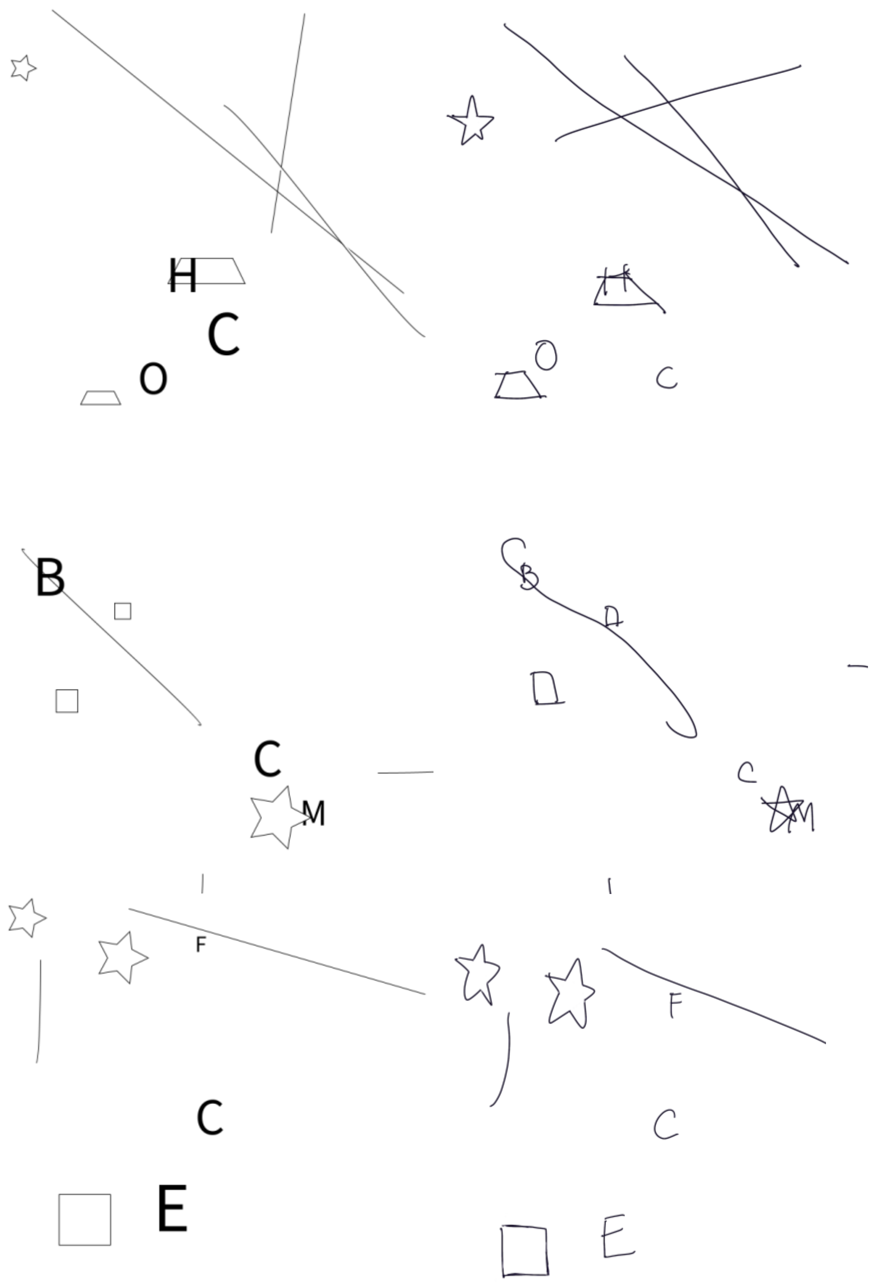
a. Thumb



b. Index finger



c. Middle finger



d. Pen

Appendix 2: Data Analysis of similarity

Tool	Element	Absolute position	Relative position	Size	Shape
Thumb 1	Top curve 1	3.00	3.00	3.00	2.00
	Bottom curve 2	3.00	2.00	2.00	2.00
	Straight line	0.00	0.00	0.00	0.00
	Letter J	3.00	2.00	3.00	2.00
	Letter F	3.00	2.00	3.00	3.00
	Letter O	3.00	3.00	3.00	3.00
	Circle	3.00	3.00	3.00	3.00
	Star	2.00	2.00	3.00	2.00
	Trapezoid	1.00	1.00	2.00	2.00
	Letter A	3.00	2.00	2.00	3.00
	Letter T	3.00	2.00	3.00	3.00
	Letter N	2.00	3.00	2.00	3.00
	Trapezoid	2.00	2.00	1.00	0.00
Thumb 2	Large square	2.00	2.00	3.00	3.00
	Small square	3.00	2.00	3.00	3.00
	Top curve	2.00	1.00	2.00	1.00
	Middle curve	3.00	3.00	3.00	1.00
	Bottom curve	3.00	3.00	3.00	2.00
	Large trapezoid	3.00	3.00	2.00	2.00
	Small trapezoid	2.00	2.00	2.00	2.00
Thumb 3	Left curve	3.00	3.00	3.00	1.00
	Short curve	1.00	1.00	3.00	3.00
	Straight line	3.00	3.00	2.00	3.00
	Circle	2.00	2.00	2.00	3.00
	Letter U	3.00	3.00	2.00	3.00
	Letter Y	2.00	2.00	2.00	3.00
	Letter B	2.00	1.00	2.00	3.00
	Long straight line 1	3.00	3.00	2.00	3.00
	Curve 1	3.00	2.00	3.00	1.00

Index Finger 1	Short straight line 2	2.00	3.00	2.00	3.00
	Square	2.00	2.00	2.00	3.00
	Letter U	3.00	3.00	2.00	3.00
	Letter P	3.00	3.00	2.00	3.00
	Letter L	2.00	2.00	3.00	2.00
	Large circle 1	2.00	1.00	1.00	3.00
	Small circle 2	1.00	1.00	2.00	3.00
	Trapezoid	2.00	3.00	2.00	2.00
	Letter B	2.00	1.00	2.00	3.00
	Letter Z	2.00	3.00	0.00	0.00
Index Finger 2	Letter Q	3.00	3.00	3.00	3.00
	Left curve 1	2.00	2.00	2.00	2.00
	Right curve 2	2.00	1.00	1.00	0.00
	Large star 1	2.00	3.00	2.00	2.00
	Small star 2	2.00	2.00	3.00	3.00
	Straight line	1.00	1.00	1.00	0.00
	Large star 1	3.00	3.00	3.00	2.00
	Small star 2	1.00	3.00	2.00	1.00
	Straight line	1.00	3.00	3.00	3.00
Index Finger 3	Letter J	2.00	3.00	2.00	2.00
	Letter H	2.00	3.00	2.00	3.00
	Left curve 1	2.00	2.00	2.00	2.00
	Right curve 2	3.00	3.00	3.00	2.00
	Trapezoid	1.00	2.00	1.00	2.00
	Letter O	3.00	3.00	3.00	3.00
Middle	Letter M	3.00	3.00	2.00	3.00

Finger 1	Letter U	3.00	2.00	3.00	3.00
	Letter E	2.00	3.00	2.00	3.00
	Curve	1.00	2.00	2.00	1.00
	Long straight line 1	2.00	2.00	2.00	2.00
	Short straight line 2	3.00	3.00	2.00	2.00
	Star	2.00	3.00	2.00	2.00
	Small circle 1	1.00	1.00	0.00	0.00
	Large circle 2	2.00	1.00	3.00	3.00
	Letter F	3.00	3.00	2.00	3.00
	Letter L	2.00	2.00	3.00	2.00
	Square	2.00	1.00	3.00	3.00
	Small circle	3.00	2.00	1.00	3.00
	Large circle	3.00	2.00	3.00	3.00
	Long curve	3.00	2.00	2.00	2.00
	Short curve	3.00	2.00	1.00	2.00
Middle Finger 2	Long straight line	3.00	3.00	1.00	3.00
	Short straight line	3.00	2.00	2.00	2.00
	Square	3.00	3.00	2.00	3.00
	Letter U	2.00	3.00	3.00	3.00
	Letter W	3.00	2.00	3.00	3.00
	Letter S	3.00	3.00	2.00	3.00
	Top straight line 1	3.00	2.00	2.00	2.00
	Bottom straight line 2	3.00	2.00	3.00	3.00
	Shortest straight line 3	3.00	3.00	2.00	3.00
Middle Finger 3	Left star 1	3.00	2.00	3.00	3.00
	Right star 2	3.00	3.00	3.00	3.00

	Long straight line 1	3.00	3.00	2.00	3.00
	Vertical straight line 2	1.00	1.00	2.00	1.00
	Straight line 3	2.00	3.00	3.00	3.00
	Star	2.00	3.00	2.00	3.00
	Large trapezoid	3.00	2.00	3.00	3.00
	Small trapezoid	3.00	3.00	3.00	2.00
	Letter H	3.00	2.00	3.00	3.00
	Letter C	2.00	1.00	2.00	3.00
Pen 1	Letter O	2.00	2.00	3.00	3.00
	B	3.00	3.00	2.00	3.00
	C	3.00	2.00	2.00	3.00
	M	3.00	2.00	3.00	3.00
	Long curve	3.00	3.00	3.00	2.00
	Bottom curve	3.00	3.00	3.00	2.00
	Straight line	2.00	2.00	2.00	2.00
	Star	3.00	3.00	2.00	2.00
	Square 1	3.00	2.00	3.00	3.00
Pen 2	Square 2	3.00	3.00	3.00	3.00
	Left star 1	3.00	3.00	2.00	3.00
	Right star 2	3.00	3.00	3.00	3.00
	Long straight line	3.00	3.00	2.00	3.00
	F	3.00	3.00	3.00	3.00
	C	3.00	3.00	3.00	3.00
	E	3.00	3.00	3.00	3.00
	Curve	2.00	3.00	3.00	2.00
Pen 3	Square	3.00	3.00	3.00	3.00