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Study of improvement in writing skill of non-dominant hand in stroke patients with paralyzed dominant hand: a comparative study with healthy subjects and orthopedic patients with impaired dominant hand

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Abstract

Purpose: The purpose of this study is to clarify improvement in writing skills by non-dominant hand in cerebrovascular accident (CVA) patients with paralyzed dominant hand.

Subjects: Twenty-nine CVA patients (age: 71.7 ± 11.3 years), 20 orthopedic patients (age: 6 7.0± 9.8 years) and 32 healthy subjects (age: 70.4 ± 13.8 years) participated in the study. All subjects were right-handed. Patients with cognitive dysfunction were excluded from this study.

Methods: The task was to trace over the outline of 8 types of symbols presented over the tablet screen. The successive tracings of the 8 types of symbols were counted as 1 session, which was repeated 10 times consecutively. Acquired data included total tracing time, difference in length between the test symbol circumference and trajectory length(difference in length), pen pressure during performance （pen pressure）, difference in area between the test symbol and the subject traced (difference in area), and the force exerted by the fingers against the pen during writing (grip force).

Results: There was no significant within-group difference in any of the 3 groups (CVA patients, orthopedic patients, and healthy subjects). In between-group comparison, significant differences were observed more often in the latter half of the sessions than in the former half, where the CVA subjects showed longer total tracing time, higher pen pressure and grip force, and larger differences in length and area than the healthy subjects and the orthopedic subjects.

Discussion: In some parameters, there were significant differences in the results of the latter half of the 10 sessions. It was assumed that the CVA subjects got skillful slower than healthy subjects and orthopedic patients.

Key words:

writing skill, CVA patient, non-dominant hand

Introduction

Writing is a fundamental skill that impacts various fields of one's everyday-life and professional performance[1)]. Though the widespread use of keyboards, writing is still an important means of communicating through space and time[2)]. Writing is a complex human activity, involving an intricate blend of cognitive and perceptual-motor components[3)]. Despite the importance of writing in everyday-life, virtually no literature can be found that documents the extend and range of everyday writing performance and ability among the healthy elderly[4)].

Independent finger movement is lost following damage to cortical motor areas in stroke, which impairs the ability to complete many activities of daily living. It has been estimated that only 5% of persons

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following stroke recover full arm and hand function with chronic hand limitations in the remaining adults with hemiplegia[5-7].These limitations include ongoing incoordination and slowness in reach and grasp[8, 9].

The concept of intermanual transfer has important implications in therapeutic practice because the knowledge of transfer can be used in regaining or retraining some of the skills disrupted following unilateral damage to the brain, as occurs in stroke patients, or in unilateral dominant hand amputation[10]. For example, occupational therapy clients with unilateral loss of upper limb functions can practice regaining control over injured muscle or can relearn skills through the use of functional activities by taking advantage of the skills already learned by the uninjured or relatively unaffected upper limb[11].

Writing is a highly skilled and complex, coordinated motor activity which has been described as the most demanding and complex fine motor function besides drawing[12, 13]. Visual-motor integration, bilateral motor integration, motor planning, proprioception, visual perception and sustained attention are important components that contribute to complex fine motor skills like writing and drawing[12-14].

Previous studies have shown that writing time of a fixed sentence or word is prolonged, the frequency of up and down movements is decreased, measures of pen velocity are similarly decreased, measures of the regularity of the velocity profile indicate decreased fluency and automation, and various indicators of variability during repetitive writing of a constant letter or symbol are increased1[5-20]. Regarding pen pressure, it has been described in previous study that patients with writer's cramp, multiple sclerosis showed a higher pen pressure than healthy subjects[15, 21]. Endo et al.[22] measured pen pressure in the analysis of writing movement with right-sided paralysis due to a CVA, and they reported no significant difference in comparison with healthy subjects. The parameters used to evaluate the accuracy in writing performance are difference in length and difference in area jutting out from the symbol of target.[21, 23]

We chose a digitizing tablet, because tablets already have been used for analyzing handwriting to provide specific quantification[18]. Position and pressure of a specialized pen are determined on the digitizer with a high spatial and temporal resolution. These data are then saved on a PC and post-processed using computational algorithms to determine a broad variety of kinematic parameters that reflect different aspects of movement[1].

The parameters for evaluating handwriting are writing speed, pen pressure, differences in length and area, and grip force. Among these, writing speed is considered the parameter most related to improvement of writing skills[22, 24, 25].

However, in the case of a CVA patient with a paralyzed dominant hand, there is no study on the pattern peculiar to CVA of improving writing skills with the non-dominant hand. We have a clinical impression that CVA patients tend to complain of a fatigue more often than others during occupational therapy and take longer time to improve, while orthopedic patients who use non-dominant hand barely grumble about fatigue and take less time for improvement.

In this study, we comparison with three groups (CVA patients, orthopedic patients, healthy subjects) because of focused on CVA patients improvement. CVA patients have brain damage and they live by non-dominant hand because of right hemiplegia. Orthopedic patients don't have brain damage and they live by non-dominant hand. Healthy subjects don't have brain damage and they live by dominant hand.

As test materials, symbols were used instead of characters, in order to avoid effects of LBD(left brain damage)on participants' literal dysfunction, and as a test method, tracing was used to measure the accuracy of writing performance.

Methods

Subjects

Twenty-nine CVA patients (CVA patients group 〔CVA patient〕:7 male and 22 female, mean age ± SD 71.7 ± 11.3 years;), 20 orthopedic patients (orthopedic patients group〔OP〕; 6 male and 14

female, mean age ± SD: 67.0 ± 9.8 years), and 32 healthy volunteers (healthy subjects group〔HC〕;5 male and 27 female, mean age ± SD: 70.4 ± 13.8 years)participated in the study (Table 1). All subjects were right-handed. The participating orthopedic patients were the right side forearm or humeral fracture. So, their right hand had been immobilized due to the medical treatment before this study. The CVA patients participating were those with right hemiplegia due to disease-induced left brain damage. Patients, who were unable to perform the task after it was demonstrated to them once, were considered ineligible and were excluded from the study.

The study protocol was approved by the Ethics Committee of Sanda City Hospital（2008001）, and informed written consent was obtained from each subject.

Equipment

Equipment used in the study included a tablet (PTZ-2100) and a dedicated stylus pen (KP-300E-01), both from WACOM. All data acquired was stored in a personal computer, Panasonic Let's note (CF-W8FWU2JC）. In order to measure grip force, a PPS's pressure sensor (Tact Array sensor), which can be attached to a curved surface, was fixed on the grip of the stylus pen. Grip force data was recorded and stored in a personal computer, Frontier NT (KOUZIRO) (Fig. 1).

Data from the tablet and pressure sensor were synchronized for recording with the sampled with a rate at 20 Hz.

Task for the test

The tablet and the pressure sensor-equipped stylus pen were placed on the desk. The personal computers for data acquisition were positioned in a manner such that the subjects could not see the screens.

Table 1. Characteristics of participants

	CVA patients (n=29)	orthopedic patients (n=20)	healthy volunteers (n=32)
Age	71.7±11.3	67.0±9.8	70.4±13.8
Gender			
Male/Female	7/22	6/14	5/27
months post-onset	10.19±22.81	23.56±11.40	

Fig. 1. Grip force measuring writing device

During the experimental session, each subject took a wheelchair or chair sitting position with their forearms kept on the tablet on the desk. When it was difficult for the CVA patients to keep their paralyzed side on the tablet, they were allowed to have a comfortable forearm position (Fig. 2).

The assignment was to trace over the outline of 8 types of symbol presented over the tablet, from top to bottom (Fig. 3). Symbols used for the test included circles (as used in the previous studies) and 6 varieties of angular symbols. The symbol were comprising different types and directions of lines including long or short diagonal lines with a shallow curve and tapering end called “Hane” or “Harai” in Japanese, which are unique to Japanese Katakana syllabic character, in an effort to simulate Katakana that has a simple structure with less line counts. Prior to the experimental session, the examiner explained the assignment verbally to each subject followed by a demonstration using examiner’s non-dominant hand to demonstrate how to trace over the outline of the test symbols. To ensure that the task was well understood, each subject was given a trial session prior to data measurement. The subjects were instructed to start the test when the examiner clicked the start button on the tablet and asked them start, and requested them, saying” try to trace over the figures as fast and accurately as you can”.

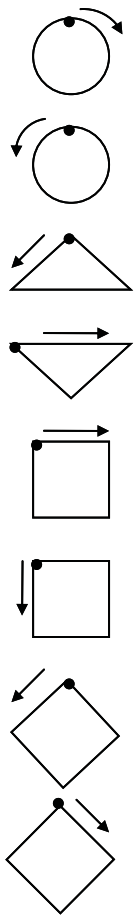

Fig. 3. Eight symbols used as models for tracing Each symbol fits into the square of 3cm

Fig. 2. Posture of measurement

Table 2. Total writing time

	group	1th(s)	3th(s)	5th(s)	7th(s)	9th(s)
1	CVA patient	4.04(1.83)	4.72(2.18)	4.50(2.18)	4.07(1.82)	4.43(2.46)
	orthopedic patient	3.87(1.64)	4.12(2.41)	4.38(1.71)	4.12(1.73)	4.87(1.69)
	healthy subject	3.49(1.73)	3.51(1.58)	3.43(1.73)	3.73(1.57)	3.85(1.78)
2	CVA patient	3.86(2.01)	4.33(2.36)	4.56(2.54)	4.02(2.14)	3.86(1.85)
	orthopedic patient	4.12(1.93)	3.96(1.96)	4.32(2.24)	3.69(1.78)	4.50(2.01)
	healthy subject	3.52(1.86)	3.05(1.65)	3.28(1.70)	3.26(1.69)	3.24(1.45)
3	CVA patient	4.29(1.97)	4.96(2.35)	4.49(2.33) ^{AB}	4.22(1.84) ^{AB}	4.43(2.26)
	orthopedic patient	4.14(1.40)	4.18(1.83)	4.65(2.15)	4.59(2.36)	4.31(2.18)
	healthy subject	3.78(1.85)	3.62(1.72)	3.23(1.58)	3.32(1.34)	3.00(1.52)
4	CVA patient	4.41(2.33)	4.58(2.12)	4.26(2.23)	4.29(1.90)	4.29(2.08)
	orthopedic patient	4.01(1.97)	4.35(1.13)	4.21(2.23)	4.15(1.35)	4.54(2.14)
	healthy subject	4.02(2.01)	3.68(1.66)	3.36(1.56)	3.79(1.69)	3.55(1.57)
5	CVA patient	4.94(2.28)	4.83(2.62)	5.34(2.65)	4.78(2.03)	4.61(2.18)
	orthopedic patient	4.20(1.89)	4.65(1.44)	5.03(2.22)	4.65(1.30)	4.73(2.00)
	healthy subject	4.28(2.24)	4.09(2.01)	3.86(1.97)	3.76(1.42)	3.33(1.86)
6	CVA patient	4.91(2.64)	4.85(2.42)	5.06(2.62)	5.04(1.84) ^{A}	4.54(2.19)
	orthopedic patient	4.60(2.12)	4.57(1.50)	4.45(2.33)	4.56(1.20)	4.38(1.30)
	healthy subject	4.44(2.29)	4.07(1.97)	3.93(1.82)	3.55(1.91)	3.63(1.12)
7	CVA patient	4.85(2.74)	5.15(2.51)	4.85(2.61)	4.95(2.26)	4.95(2.65)
	orthopedic patient	4.10(2.47)	4.47(1.92)	4.90(2.55)	4.42(2.54)	4.7(1.42)
	healthy subject	4.61(1.91)	4.11(2.11)	3.94(1.80)	3.69(1.47)	3.44(1.37)
8	CVA patient	4.71(2.37)	5.33(2.30)	4.83(2.08)	4.75(2.30)	4.68(2.17) ^{A}
	orthopedic patient	4.02(1.53)	5.17(2.57)	4.93(3.13)	4.31(1.70)	4.52(0.98)
	healthy subject	4.80(2.35)	3.74(1.70)	3.83(1.63)	3.98(1.92)	3.47(0.98)

CVA patients n=29 | orthopedic patients n=20 | healthy subjects n=32

1 ○ clockwise | 2 ○ counterclockwise | 3 △counterclockwise | 4 ▽clockwise | 5 □ clockwise | 6 □ counterclockwise | 7 ◇counterclockwise | 8 ◇clockwise

mean (SD)

A $p < 0.05$ vs. healthy subject group

B $p < 0.05$ vs. orthopedic patient group

※The result of the even number times were omitted

The successive tracings of the 8 types of symbols were counted as 1 session, which was measured 10 times consecutively, making the total number of the trials as 80. The subjects were given an interval of approximately 1 minute between sessions.

Data analysis

Acquired data included total tracing time, difference in length, pen pressure, difference in area, and grip force. Between- and within- group comparisons were made for all data acquired. One-way analysis of variance was used for statistics. In cases where homoscedasticity was not confirmed, the Kruskal-Wallis test was performed. The level of significance was set at $p < .05$.

Table 3. Pen Pressure

	group	1th(level)	3th(level)	5th(level)	7th(level)	9th(level)
1	CVA patient	120.84(46.65)	131.17(44.17)	133.57(56.05)	139.18(49.39)	141.54(45.09)
	orthopedic patient	118.85(35.83)	125.34(42.89)	128.21(42.13)	116.71(35.68)	123.45(38.58)
	healthy subject	127.60(48.54)	138.13(41.87)	136.21(42.36)	136.75(42.56)	134.89(38.11)
2	CVA patient	131.54(44.74)	148.70(43.80)	148.30(45.20)	151.50(44.94)	147.74(45.07)
	orthopedic patient	129.51(38.35)	139.18(52.64)	126.66(43.74)	122.35(35.17)	131.17(41.73)
	healthy subject	140.58(41.55)	136.27(51.59)	148.46(48.67)	146.55(41.78)	141.87(38.52)
3	CVA patient	136.23(42.58)	141.80(51.21)	150.39(42.24)	149.54(41.31)	149.60(44.53)
	orthopedic patient	127.35(33.06)	147.09(47.29)	135.57(40.63)	129.17(34.80)	135.12(36.93)
	healthy subject	143.26(42.57)	140.98(48.69)	145.28(56.88)	147.46(44.58)	146.35(43.26)
4	CVA patient	128.41(51.60)	150.69(42.11)	151.28(43.43)	152.99(40.78)	146.64(44.05)
	orthopedic patient	130.28(38.32)	137.77(55.39)	128.70(46.86)	121.58(34.17)	123.59(40.33)
	healthy subject	136.94(43.19)	140.29(50.78)	144.31(48.13)	140.63(49.63)	139.16(45.74)
5	CVA patient	132.07(44.70)	146.69(45.43)	153.95(41.26)	154.50(40.11) [B]	149.63(44.45)
	orthopedic patient	127.66(38.00)	139.72(57.57)	127.14(46.37)	119.66(37.11)	124.26(41.66)
	healthy subject	142.58(43.80)	140.15(49.21)	146.67(52.64)	148.46(48.19)	145.74(41.61)
6	CVA patient	138.77(50.27)	148.61(37.43)	153.79(39.56)	150.99(40.22) [B]	149.30(40.15)
	orthopedic patient	124.00(40.96)	139.16(56.06)	129.68(46.34)	120.65(33.56)	118.41(37.76)
	healthy subject	147.41(44.28)	142.69(49.88)	150.07(49.49)	149.82(46.40)	147.75(44.33)
7	CVA patient	142.39(38.30)	153.25(48.34)	155.94(40.70)	151.55(37.41)	151.63(36.74)
	orthopedic patient	112.40(40.28)	140.98(63.02)	124.99(48.85)	125.30(33.25)	116.29(47.20)
	healthy subject	151.54(48.56)	143.40(50.19)	151.09(49.68)	146.32(48.74)	148.94(45.14)
8	CVA patient	133.72(42.32)	146.06(52.71)	143.67(45.35)	144.19(48.83)	140.03(52.86)
	orthopedic patient	113.25(50.75)	139.73(64.10)	117.00(61.02)	118.28(46.93)	126.6(43.59)
	healthy subject	147.58(45.47)	143.94(51.96)	139.87(43.98)	144.89(52.23)	147.91(46.60)

CVA patients n=29 / orthopedic patients n=20 / healthy subjects n=32

1 ○ clockwise; 2 ○ counterclockwise; 3 △counterclockwise; 4 ▽clockwise; 5 □ clockwise; 6 □ counterclockwise; 7 ◇counterclockwise; 8 ◇clockwise

mean (SD)

[A] $p < 0.05$ vs. healthy subject group

[B] $p < 0.05$ vs. orthopedic patient group

※The result of the even number times were omitted

Results

Mean values and standard deviations for each parameter are shown in Tables 2-6.

There was no within-group difference in any of the 3 groups (CVA patient, OP and HC).

The results of the between-group comparisons are shown as follows.

Total tracing time (Table 2)

No significant difference was observed among the 3 groups for any of the test symbols in 1st-4thsessions. CVA patient took significantly longer than other groups for the triangle (when traced counterclockwise) in the 5th session; the triangle (counterclockwise) in the 6th session; and the triangle

Table 4. Distance in length

	group	1th(㎜)	3th(㎜)	5th(㎜)	7th(㎜)	9th(㎜)
1	CVA patient	74.45(19.76)	79.82(29.24)	73.19(25.58)	79.32(26.09)	77.02(23.92)
	orthopedic patient	71.45(24.95)	75.94(27.64)	70.76(17.93)	74.08(23.29)	70.47(17.82)
	healthy subject	68.06(16.33)	71.18(20.39)	71.97(20.02)	74.15(24.33)	72.98(20.08)
2	CVA patient	15.71(20.72)	13.50(16.49)	9.49(9.22)	12.46(15.35)	13.53(17.63)
	orthopedic patient	15.89(13.99)	15.57(14.35)	10.91(5.89)	13.83(13.47)	13.75(13.97)
	healthy subject	10.45(6.81)	13.90(15.23)	9.19(4.23)	12.94(12.92)	7.42(3.30)
3	CVA patient	22.73(7.42)	23.15(7.47)	23.83(9.75)^{B}	23.70(9.38)^{AB}	22.52(5.11)^{AB}
	orthopedic patient	21.75(6.75)	20.78(9.43)	20.81(9.44)	21.00(7.26)	18.06(5.98)
	healthy subject	16.07(12.88)	15.55(13.02)	12.84(9.41)	12.14(7.62)	12.10(8.77)
4	CVA patient	23.03(13.05)	20.21(7.10)	22.31(7.84)^{B}	24.53(9.30)	24.78(7.22)^{A}
	orthopedic patient	26.67(6.04)	24.30(7.07)	25.28(7.45)	25.55(8.49)	24.23(6.81)
	healthy subject	22.32(5.81)	21.95(4.24)	18.67(7.61)	20.33(8.21)	19.04(9.03)
5	CVA patient	23.42(9.67)	26.85(9.41)	25.37(8.98)	26.13(12.61)	25.62(7.62)
	orthopedic patient	26.74(5.00)	28.61(7.11)	26.96(6.31)	25.97(4.78)	26.24(3.85)
	healthy subject	29.10(4.84)	27.072(4.00)	25.80(3.68)	25.89(4.12)	26.10(4.64)
6	CVA patient	10.57(15.98)	10.87(12.43)	8.15(6.30)	9.76(10.29)	8.46(7.22)^{A}
	orthopedic patient	11.65(10.98)	6.70(5.32)	8.12(6.15)	8.27(7.48)	6.12(3.70)
	healthy subject	9.01(6.15)	9.59(8.50)	5.49(4.12)	7.83(4.36)	4.48(3.35)
7	CVA patient	10.03(10.47)	13.30(16.38)	10.02(6.89)	11.59(12.49)	10.07(5.69)
	orthopedic patient	14.36(23.79)	10.12(9.71)	13.46(18.63)	9.53(7.17)	14.51(22.94)
	healthy subject	6.82(4.35)	8.25(6.82)	7.25(9.69)	7.37(10.06)	6.97(4.1)
8	CVA patient	12.41(17.21)	11.59(15.28)	10.98(16.55)	13.03(17.07)	10.86(18.36)
	orthopedic patient	24.91(22.04)	16.73(11.19)	20.59(21.72)	19.85(18.25)	13.77(5.61)
	healthy subject	14.39(7.63)	13.02(6.61)	11.80(8.38)	10.91(7.21)	12.31(7.00)

CVA patients n=29 / orthopedic patients n=20 / healthy subjects n=32

1 ○ clockwise; 2 ○ counterclockwise; 3 △counterclockwise; 4 ▽clockwise; 5 □ clockwise; 6 □ counterclockwise; 7 ◇counterclockwise; 8 ◇clockwise

mean (SD)

A $p<0.05$ vs. healthy subject group

B $p<0.05$ vs. orthopedic patient group

※The result of the even number times were omitted

(counterclockwise) in the 7th session. CVA patient took significantly longer than HC for the circle (counterclockwise) in the 6th session; the square (counterclockwise) in the 7th session; the square (counterclockwise) and diamond (clockwise and counterclockwise) in the 8th session; the diamond (clockwise) in the 9th session; and the circle (counterclockwise), triangle (counterclockwise), inverted triangle (clockwise), and diamond (clockwise) in the 10th session.

Pen pressure (Table 3)

No significant difference was observed among the 3 groups for any of the test symbols in 1st-5th and 8th-10th sessions. CVA patient showed significantly higher pen pressure than OP for the triangle (counterclockwise) and square (clockwise) in the 6th session, and the square (clockwise and counterclockwise) in the 7th session.

Difference in length (Table 4)

No significant difference was observed among the 3 groups for any of the test symbols in 1st-1rdand

Table 5. Difference in Area

	group	1th(㎟)	3th(㎟)	5th(㎟)	7th(㎟)	9th(㎟)
1	CVA patient	84.16(71.92)	57.26(34.76)	52.15(28.74)	57.54(36.65)	66.08(35.04)
	orthopedic patient	55.31(34.31)	79.02(67.42)	65.60(34.25)	54.38(32.47)	61.97(19.87)
	healthy subject	68.73(77.11)	52.52(31.67)	55.70(29.24)	60.21(20.91)	61.04(21.41)
2	CVA patient	51.52(30.98)	63.40(50.90)	67.23(59.09)	62.23(66.12)	63.22(23.45)
	orthopedic patient	51.27(35.20)	53.6(27.07)	61.75(28.24)	50.38(18.55)	52.34(20.61)
	healthy subject	59.94(31.06)	59.50(36.41)	64.69(35.01)	52.91(21.56)	47.09(21.91)
3	CVA patient	59.12(68.57)	46.26(34.29)	42.31(36.62)	39.00(28.65)	51.49(49.24)[A]
	orthopedic patient	52.77(35.38)	35.77(33.97)	43.19(41.78)	45.48(38.63)	24.30(19.91)
	healthy subject	23.91(18.10)	22.02(14.34)	33.93(36.42)	31.16(24.18)	21.80(13.88)
4	CVA patient	60.83(32.96)	56.68(33.36)	61.84(28.77)	59.14(24.23)[B]	45.55(28.34)
	orthopedic patient	46.67(25.70)	45.18(24.70)	44.69(25.20)	39.99(25.39)	44.99(24.31)
	healthy subject	44.36(25.77)	41.64(28.88)	47.02(29.32)	42.95(22.20)	39.48(19.63)
5	CVA patient	131.24(53.15)	138.87(50.67)	131.42(64.39)	142.30(72.71)	143.86(37.56)[A]
	orthopedic patient	127.69(32.03)	128.92(28.07)	128.93(34.05)	135.32(21.98)	131.29(22.58)
	healthy subject	136.24(33.24)	125.88(29.61)	121.37(24.03)	123.71(24.03)	117.16(23.75)
6	CVA patient	138.13(59.39)	143.89(67.24)	136.68(45.25)	135.92(44.23)	146.50(39.90)[A]
	orthopedic patient	152.79(41.04)	126.39(33.02)	120.90(28.18)	130.95(29.23)	123.38(21.47)
	healthy subject	133.43(30.62)	135.02(22.91)	125.9(22.50)	122.40(24.95)	121.22(18.93)
7	CVA patient	65.04(82.17)	86.64(84.89)	63.61(57.51)[A]	52.36(39.50)	63.30(31.18)[A]
	orthopedic patient	109.86(108.17)	56.72(25.78)	90.39(98.84)	60.28(25.59)	89.77(97.32)
	healthy subject	48.37(31.30)	65.72(47.83)	53.59(25.61)	75.66(74.94)	61.05(26.82)
8	CVA patient	78.85(94.25)	48.21(75.24)	66.96(85.98)	50.41(51.44)	41.83(26.55)
	orthopedic patient	100.31(132.71)	25.02(15.09)	26.3(24.01)	42.87(89.89)	17.20(14.92)
	healthy subject	17.48(18.53)	20.28(15.45)	23.50(20.06)	22.43(14.54)	22.34(15.64)

CVA patients n=29 / orthopedic patients n=20 / healthy subjects n=32

1 ○ clockwise　2 ○ counterclockwise　3 △counterclockwise　4 ▽clockwise　5 □ clockwise　6 □ counterclockwise　7 ◇counterclockwise　8 ◇clockwise

mean (SD)

[A] $p < 0.05$ vs. healthy subject group

[B] $p < 0.05$ vs. orthopedic patient group

※The result of the even number times were omitted

6th sessions. CVA patient showed a significantly larger difference in length than the other groups for the diamond (counterclockwise) in the 4th session and the triangle (counterclockwise) in the 9th session. CVA patient showed a significantly larger difference in length than OP for the triangle (counterclockwise) and inverted triangle (clockwise) in the 5th session, the square (clockwise) in the 7th session, and the inverted triangle (clockwise) in the 8th session. CVA patient showed a significantly larger difference in length than HC for the diamond (clockwise) in the 8th session, and the inverted triangle (clockwise) and square (counterclockwise) in the 9th session.

Difference in area (Table 5)

No difference was observed among the 3 groups for any of the test symbols in the 6th session. CVA patient showed a significantly larger difference in area than the other groups for the diamond (counterclockwise) in the 4th session, the triangle (counterclockwise) in the 8th session, and the triangle (counterclockwise) in the 9th session. CVA patient showed a significantly larger difference in area than HC for

Table 6. Grip Force

	group	1 t h(KPa)	3 t h(KPa)	5 t h(KPa)	7 t h(KPa)	9 t h(KPa)
	healthy subject	1343.60 (3381.65)	1906.10(3861.36)	1936.68(4184.89)	1914.31(4299.75)	573.55(679.79)
1	orthopedic patient	735.61(937.30)	894.88(933.07)	866.44(921.46)	825.96(932.34)	1064.68(943.92)
	CVA patient	2887.88(9830.72)	707.99(803.90)	740.19(926.02)	995.34(1229.06)	1105.25(1579.00)
	healthy subject	1585.61 ((3497.01)	1965.24(4006.22)	2030.99(4372.27)	448.00(614.50)	507.16(639.18)
2	orthopedic patient	665.14(881.37)	950.88(1009.06)	875.04(968.80)	822.99(869.12)	1010.32(921.10)
	CVA patient	2821.37(9583.56)	695.59(798.86)	1721.61(4598.30)	1035.74(1368.26)	2336.12(5604.64)A
	healthy subject	1296.11(3343.16)	1537.45(3482.17)	747.19(1032.99)	556.05(809.11)	1155.36(3180.51)
3	orthopedic patient	896.86(1491.43)	663.70(655.57)	798.33(803.78)	787.74(768.72)	855.86(605.21)
	CVA patient	4785.32(12884.47)	768.45(844.76)	989.43(1503.68)	903.40(1065.62)	1085.47(1164.24)A
	healthy subject	719.58(817.46)	1360.00(2529.31)	1261.46(2713.86)	1412.15(3107.48)	1185.96(3436.19)
4	orthopedic patient	840.60(1187.45)	738.19(702.12)	828.48(864.90)	621.44(496.32)	807.26(599.26)
	CVA patient	2999.21(9551.09)	703.28(808.91)	722.47(832.73)	791.32(999.69)	1114.26(1334.28)A
	healthy subject	1384.66(3410.66)	1944.90(3919.50)	1267.91(2739.50)	1969.71(4291.01)	368.14(514.75)
5	orthopedic patient	809.95(1162.78)	736.11(693.28)	728.07(767.13)	592.81(502.17)	806.18(535.06)
	CVA patient	3124.98(9821.65)	715.70(791.68)	733.17(861.92)	867.00(1019.12)	987.09(1229.60)A
	healthy subject	671.34(725.77)	813.03(973.07)	738.79(1024.28)	599.00(825.26)	353.45(489.41)
6	orthopedic patient	677.31(1092.09)	720.85(694.63)	545.38(463.82)	596.71(509.18)	779.40(508.34)
	CVA patient	3344.60(10313.60)	746.41(865.30)	761.36(870.85)	952.21(1085.70)	1053.66(1429.51)A
	healthy subject	802.07(957.81)	802.19(1020.26)	710.57(1045.54)	462.97(631.52)	365.67(487.29)
7	orthopedic patient	576.18(827.76)	688.49(654.68)	545.27(455.02)	596.90(510.06)	722.65(493.97)
	CVA patient	3351.51(10321.72)	717.90(871.45)	745.08(894.17)	761.55(839.97)	1102.14(1560.95)
	healthy subject	672.07(754.80)	750.08(963.72)	611.32(811.09)	372.66(697.80)	325.02(448.63)
8	orthopedic patient	516.59(740.49)	792.80(909.68)	496.91(456.07)	596.75(447.80)	730.89(497.83)
	CVA patient	3329.96(10325.07)	782.87(893.93)	599.36(581.81)	2686.94(8020.40) A	915.11(1351.14)A

CVA patients n=29 orthopedic patients n=20 healthy subjects n=32

1 ○ clockwise 2 ○ counterclockwise 3 △counterclockwise 4 ▽clockwise 5 □ clockwise 6 □ counterclockwise 7 ◇counterclockwise 8 ◇clockwise

mean (SD)

A $p<0.05$ vs. healthy subject group

B $p<0.05$ vs. orthopedic patient group

※The result of the even number times were omitted

the triangle (counterclockwise) in the 1st and 1rd sessions; the triangle (counterclockwise) and inverted triangle (clockwise) in the 2nd session; the circle (counterclockwise) and triangle (counterclockwise) in the 4th session; the diamond (counterclockwise) in the 5th session; the circle (clockwise) in the 8th session; the square (clockwise and counterclockwise) and diamond (counterclockwise) in the 9th session; and the triangle (counterclockwise), square (clockwise and counterclockwise), and diamond (counterclockwise) in the 10th session. CVA patient showed a significantly larger difference in area than OP for the triangle (counterclockwise) in the 7th session.

Grip force (Table 6)

No significant difference was observed among the 3 groups for any of the test symbols in 1st-5thsessions. CVA patient showed significantly higher grip force than other groups for the inverted triangle

(clockwise) in the 10th session, but there was no difference in multiple comparisons. CVA patient showed a significantly higher grip force than HC for the circle (counterclockwise) in the 6th session; the diamond (counterclockwise) in the 7th session; the circle (counterclockwise), triangle (counterclockwise), inverted triangle (clockwise), and diamond (clockwise and counterclockwise) in the 8th session; the circle (counterclockwise), triangle (counterclockwise), inverted triangle (clockwise), square (clockwise and counterclockwise), and diamond (clockwise and counterclockwise) in the 9th session; and the circle (clockwise and counterclockwise), square (counterclockwise), and diamond (clockwise) in the 10th session.

The results of the between-group comparisons mentioned above are shown in Figure 4.

Significant differences were observed more often in the latter half of the sessions than in the former half.

Discussion

It is thought that there are three elements of writing skill[22, 24, 25]. First is writing speed that is considered the parameter most related to improvement of writing skills. Second is accuracy that can be measured as difference in length and area. Third is power which needs to use a pen that can be measured by pen pressure and grip force. It was found in the previous study that improvement in writing performance lead to a shorter duration in writing, decreased pen pressure, and improved accuracy[22, 24, 25]. In this study which consists of 10 consecutive sessions of tracing, performance of the subjects was assumed to improve if the total tracing time got shorter, pen pressure got decreased, and accuracy such as difference in trajectory length and area got decreased. We chose those parameters which showed significant difference in the between-group comparison at least 3 times in 10 sessions,

Since we considered that the procedure of picking up the trials that showed statistical significance three times in ten sessions was sufficient enough to indicate real improvement.

Improvement during the 10 consecutive tracings of symbols

Of the 10 consecutive sessions of tracing, there was no significant within-group difference in any of the 3 groups (CVA patient, OP, and HC). However, in the comparison with the HC, the number of significant trials which CVA patient showed in the first half (1st-5th) of the session was only nine, whereas that in the latter half of the session was as many as 40. Similarly, in the comparison with the OP, the number of significant trials which CVA patient showed in the first half (1st-5th) of the session was only five, while that in the latter half (6th-10th) of session was 14.

As a result, in between-group comparison, significant difference was observed more often in the latter half of the sessions than in the former half. CVA patient showed longer tracing time, higher pen pressure, larger difference in trajectory length and area than HC and OP. All these differences indicated that CVA patient showed clumsiness compared with other subject groups. (Fig.4).

Next, we will proceed to discuss the three elements of the writing skill.

Tracing time

Fig5 shows the result of total tracing time of 3 groups for the diamond (clockwise) in 2nd and 9th. There was significant difference between CVA patient and HC in 9th session while there was no difference among the 3 groups in 2nd session. In the previous studies, writing speed is considered the parameter most related to improvement of writing skills[22, 24]. Therefore, it is assumed that CVA patient got skillful slower than HC in our study.

Accuracy

Fig6 shows the result of difference in length of 3 groups for the diamond (clockwise) in 2ndand 9th.

Akezaki et al.[26] studied writing performance to compare the effect by tracing and transcribing practice

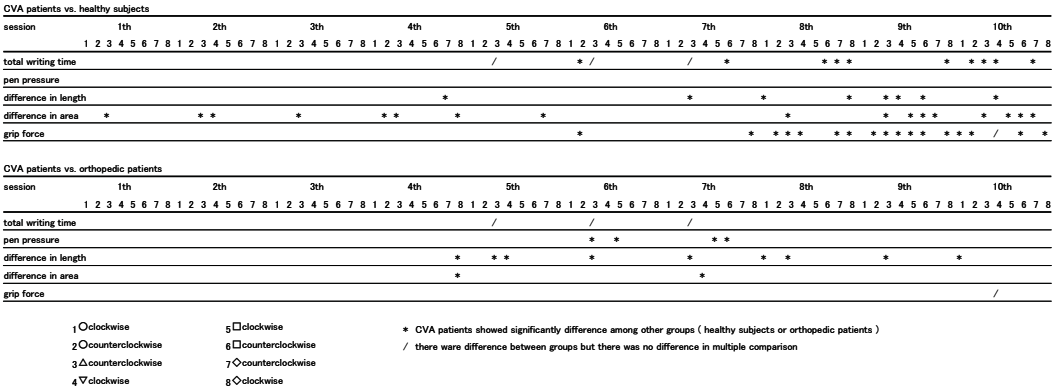

Fig. 4. List of item where difference is admitted by the comparison between group
the difference was observed more often in the latter half of the sessions than in the former half, where the CVA patient group showed longer duration of writing, higher pen pressure, larger difference in length and area than the healthy subject group and the orthopedic patient group

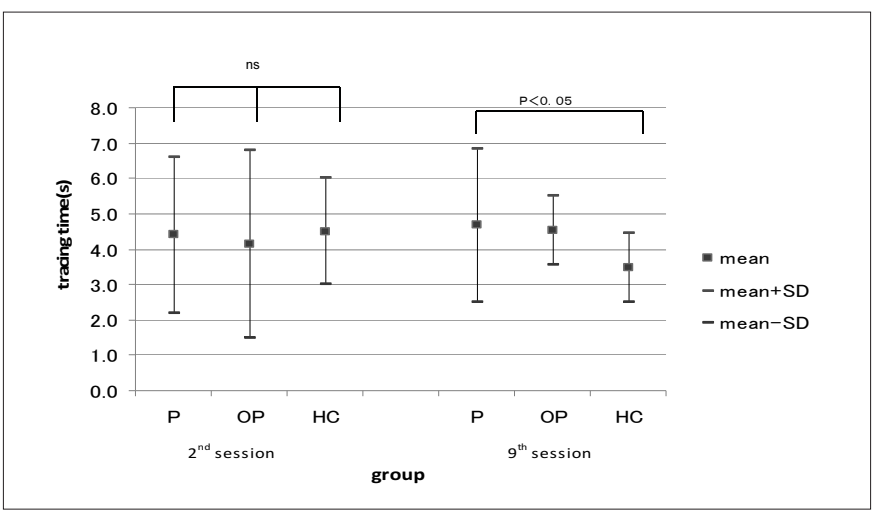

Fig. 5. Total tracing times in 2nd session and 9th session for 3groups

on the healthy subjects, and reported significant improvements in the accuracy such as decipher subject's handwriting. And duration of handwriting as a result of tracing practice despite a short period of time. Marquardt et al.[20] in the research intended for healthy subjects, described that visual feedback controls immediate motor output, based on which, repetition of such control can advance motor learning. In our study, CVA patient showed larger differences in length and area than HC and OP for latter half of the session during writing. While HP and OP can control immediate motor output by the repetition of writing, CVA patient controls more slowly than other groups.

Power to use a pen

Pen pressure

Wang[27] showed that patients with Parkinson's disease have a higher pen pressure than healthy subjects in drawing spiral curves. Then patients with writer's cramp have higher pen pressure than the healthy subjects[15, 28, 29]. Endo et al.[22] described that the healthy people were required a decreased pen pressure and motion of the fingertip toward to trace characters accurately and rapidly. Thus, in the assignment presented during this study with the instruction "trace as fast and accurately as you can," it was predicted

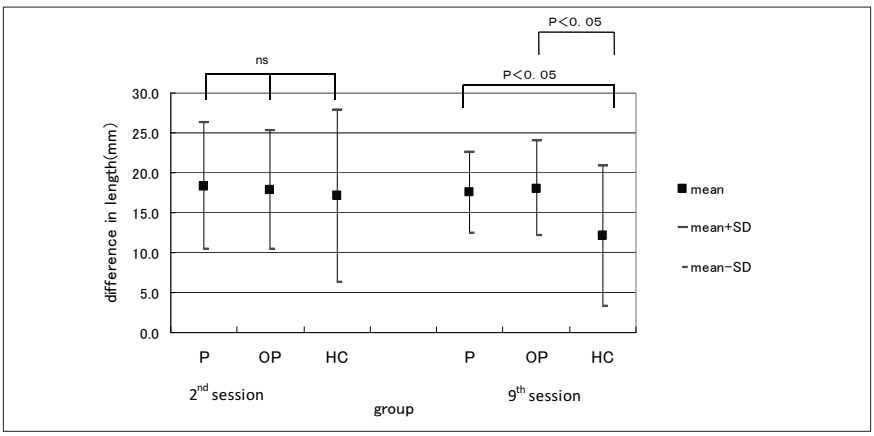

Fig. 6. Difference in length in 2nd session and 9th session for 3groups

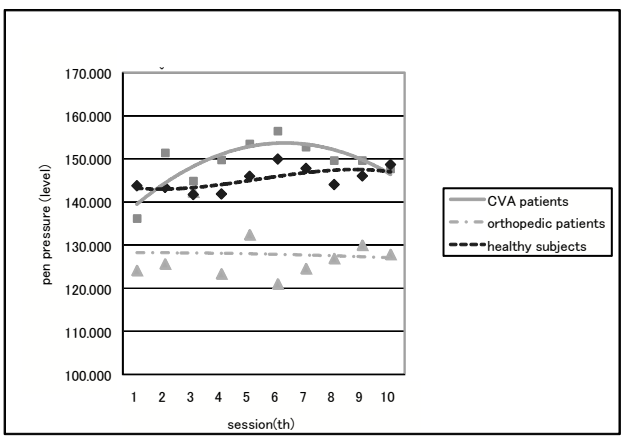

Fig. 7. Change of pen pressure

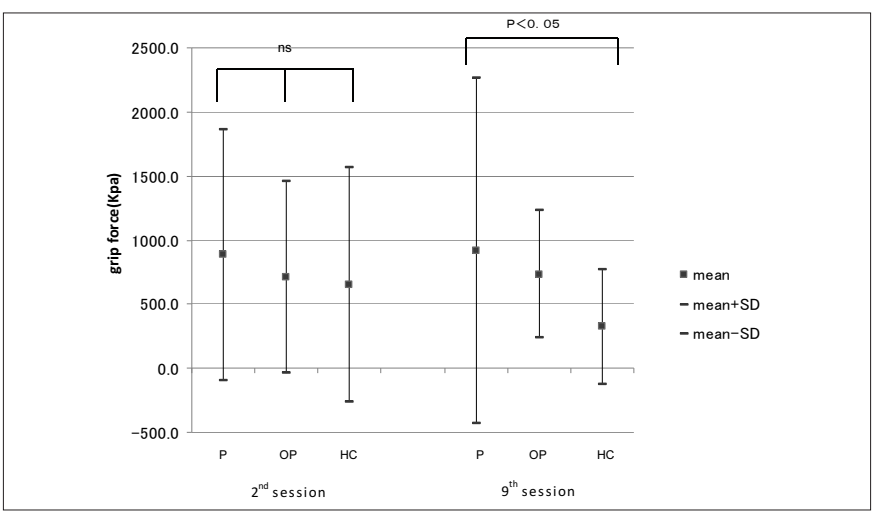

Fig. 8. Grip force in 2nd session and 9th session for 3groups

that pen pressure would become lower as writing performance improves. There is an interesting experiment performed by Rueckriegel et al.[1] on the change of pen pressure in the course of a human growth. Pen pressure increases as one grows, and then starts decreasing after reaching a plateau at the age of 15. Hashizume et al.[30] measured the change of pen pressure in the course of human development and described that pen pressure increases as one grows until the age of 12. Judging from these two findings, it is assumed that pen pressure increases as one grows for a certain period of time, and then starts decreasing. Among the test results in this study, the mean pen pressure with the triangle (clockwise) is shown in Fig. 7, from which it can be observed that pen pressure increases and then starts decreasing in all three groups. OP reached its highest point fastest, which then started decreasing earlier than the other groups. CVA patient shows a longer curve of increased pen pressure compared to other groups and higher pressure than HC. According to Endo et al.[22], there was no significant difference in the pen pressure during the tracing practice between CVA patient and healthy subjects. However, Endo et al.[22] performed the drawing only once. In our study, where the performance was repeated as many as 10 times consecutively, the results observed were similar to the ones described by Rueckriege[11] that pen pressure first increased and then decreased. Judging from the above, it is assumed that all three groups improve in pen pressure, OP is quicker in improvement, and CVA patient shows a higher increase of pen pressure than the other groups. It is assumed that OP improved quickly, because they have no physical problem other than the immobilized dominant hand and they perform their everyday activities with their non-dominant hand, thereby making them accustomed with its use. As HC had little chance to use their non-dominant hand, it is assumed that OP is the most skillful in writing with the non-dominant hand, from the point of view of proficiency.

Grip force

Fig8 shows the result of Grip force of 3 groups for the diamond (clockwise) in 2nd and 9th.There was significant difference between CVA patient and HC in 9th session while there was no significant difference among the 3 groups in 2nd session.

As for grip force, Hermsdorfer[19] shows in his comparison study that patients with writer's cramp were higher in grip force than the healthy subjects. He also studied the relationship between pen pressure and grip force, and his result revealed that there was a positive correlation between pen pressure and grip force in patients with writer's cramp but not in healthy subjects. Baur[15, 29, 31] reported that patients with writer's cramp showed a decrease in grip force after handwriting training and that grip force can be a useful parameter to evaluate handling a pen by patients with writer's cramp. Unfortunately, a study on the grip force during writing performance by the CVA patients with non-paralyzed/non-dominant hand has not been performed. In our study, CVA patient showed higher grip force than HC and OP. It was shown that CVA patient needs strong power to use a pen during writing. This assumption agrees with our clinical impression that CVA patient tend to complain of a fatigue.

In our study, the relationship between CVA patients' writing skill and grip force was unclear. Further study is needed on this matter.

Judging from the above results, it is assumed that HC and OP have been improving in proficiency by learning and adjusting in writing skill in the course of 10 sessions, although no statistically significant difference was found in the within-group comparison. On the other hand, CVA patient takes a longer time to learning writing skill. The delay in learning in the CVA patients, which we had been in the clinical impression, was verified in this study.

Limitations of Research

In this study, the ratio of male is few. It is not this ratio though there are a lot of female in the prevalence of CVA and forearm and humeral fracture. It has to expand male's data in the future.

Conclusion

In order to analyze how the CVA patients progress in handwriting when exchange the dominant hand, the duration of writing performance, trajectory length, area enclosed by the lines drawn by the subjects, pen pressure, and grip force of the pen through the subjects' tracing over the outline of test symbols were measured. In comparison with the healthy subjects and the orthopedic group as controls, no within-group difference was observed in the results of 10 times practice. In between-group comparison, some parameters showed significant differences in the latter half of 10 times practice. The between-group difference indicated slower improvements by CVA patient. Judging from the results of significant difference in pen pressure, it was found that all three groups improved in writing performance, where OP was faster and CVA patient slower.

More data should be accumulated on the relationship between the CVA patient's writing skill and grip force and future study is expected on this matter.

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