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Review Article

Health Correlates of Handwriting Instruments: From the Finger to the Brain

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Abstract

Early research on writing instruments mostly focused on ergonomic designs for education and penmanship, using mainly hard-tip pens. The second stage of analysis moved on to behavioral and perceptual effects associated with the writing tasks. The third phase focused on analyzing the soft-tip Chinese brush with current efforts concentrated on the neural and cognitive correlates of both the hard and soft instruments. In the latest evolution of writing tools comes the introduction of finger-writing. The present study compares the cognitive-neural mechanisms and activities during handwriting with hard-tip and soft-tip writing instruments: the Chinese Brush and Ball-Point Pen. We also adopted Chinese and English scripts as writing materials sharing the visual properties of Font Style and Stroke Order in a copying task. ERP results show that during writing, Brush is more active over Ball-Pen in the Parietal Cortex at N100 ($F(1, 22) = 16.45$, $P < .0001$). These Parietal results also show that the somatosensory (tactile) feedback mechanism is involved in a brain region that is associated with multisensory experience during memory retrieval and stimulus recognition. No significant interaction existed between the Brush and Ball Pen over character properties of Font Style and Stroke Order. The results suggest that the use of the Brush and Ball-Pen elicits distinct distributed activating patterns of neural mechanisms in the brain. Including Finger Writing as the third major writing instrument, we reviewed the varied positive benefits that are associated with these instruments in the areas of health, therapy, rehabilitation and behavioral change. It has solid health benefits based on findings from behavioral, cognitive and neuroscience.

The Theory of Handwriting

Handwriting consists of three main components: the hand, the writing instrument, and the paper or surface of writing material. Design for improving the writing skills and performance centers around these three elements and their interactions for enhancing writing comfort, legibility, efficiency, and motivation (1). The tool used during handwriting results in different forms of feedback: reactive feedback, which is activated from the hand itself, instrumental feedback, from the action of the writing instrument, and operational feedback, from the resulting handwriting traces on the paper (2,3). Moreover, skill learning such as handwriting occurs as a result of motor control mechanisms interfacing the motor displacements relative to the spatiotemporal coherence between mind-body movements and its instrumental sensory feed backs during the task. This displacement control process is mediated by neuronal detector mechanisms (4) as well as a full spectrum of behavioural feedback mechanisms (5) underlying the characters and letters reading and handwriting. The theoretical framework for brush calligraphy is threefold (6,7). The first is the sensory feedback: the individual receives sensory feedback from the graphic record while practicing calligraphy. Second is the bio-emotional feedback: calligraphy involves the movement of the arms and the body as the guide to regulate their movements. Finally, the cognitive feedback: the subjective experiences of heighted attention, alertness, and quickened responses during the writing acts (8). But now, finger writing for its tactile-neural feedback mechanism as well as its neural cortical involvement in the brain becomes the fourth dimension for dynamic handwriting mechanisms.

Ergonomics Effects of Writing Instrument

A conceptual framework for the design as well as performance for handwriting was suggested to include the hand control system, the writing instrument and the writing paper (9). We conducted a series of experiments to test such ergonomic principles for handwriting performance and efficiency. A study on ballpoint pen shank size for ten-year-old children using the diameters of 1/4, 3/8, and 1/2 inch revealed that the thickest ½ inch pen was the most effective for boys; the girls wrote equally well with all three sizes (10). The designs of straight and curved pen-points relative to their visual feedback properties in the writing tasks found the straight pen tips superior in writing efficiency (11,12). Another study compared pen-points tilted at an angle from the straight axis with normal straight pen-tips. The findings showed that writing time was considerably shorter with the tilted pen tips than the straight pen-points (13). Further, the location variations of the pen-points relative to the axis of the shank of the fountain pens were studied. The off-centered pen-points resulted in faster writing time and superior writing pressure than the centered tip (14). These early studies mainly focused on the task parameters of control ease, comfort, functional efficiency, and legibility. They were designed according to the behavioral feedback concept of handwriting, involved the visual, motor, kinesthetic as well as tactile sensory processing and execution. Successful findings later became the basis of new pen designs that were adopted by leading pen manufacturing companies.

Behavioral Effects of hard writing Instruments

Another area examined the functional efficiency of writing instruments. One study compared ballpoint pens, pencils, fountain pens and felt-tip pens on writing ease, legibility, and control comfort. We found the ball-pens as the most favored tool, followed by the pencil. Fountain pens were the least effective in writing practice (15). A second study compared the writing efficiency of pencils, ballpoint, fountain, and felt-tip pens by measuring writing time and pen-tip pressure. The results confirmed the overall superiority of the ballpoint for requiring the least time when performing identical writing tasks (16). The above studies mainly focused on the behavioral effects of comfort, physical legibility, point deterioration and motor accuracy. Most researches were conducted for children's handwriting and penmanship education (17). Measures in such studies in the 1960's and 1970 had included writing speed, accuracy, and pressure in motor control.

Bio-cognitive Effects of the Brush Writing Instruments

The Chinese brush is made of animal hair, tied together in small bunches and fixed into a hollow reed or very thin bamboo stem. Brush writing feed backs are activated from the hand itself, from the act of the writing brush as well as from the resulting handwriting traces on the paper (18,19,20). Brush handwriting therefore involves the sensory feedback; bio-emotional feedback; and cognitive feedback (21). In addition, there is also a neural feedback mechanism within a general system of handwriting (22). We have investigated some psychophysiological changes on the part of the practitioner. Results showed a reduction in heart rate during brush handwriting for the Chinese and non-Chinese participants as well. Other changes have included skin temperature, respiration, skin conductance and blood pressure (23). Cognitive changes associated with brush handwriting include such abilities as clerical speed and accuracy, spatial abilities, abstract reasoning, digit span, short-term memory, picture memory, figure identification and discrimination and cognitive reaction time improvement. These improved changes are affected by the visual spatial properties of the character (24). Chinese characters executed in different styles and visual-spatial forms lead to variations in the writer's behavioral responses (25).

Writing Effects of the Ball-Pen and Chinese Brush Compared

In a recent study, we compared differential effects of handwriting with the ballpoint pens and the Chinese brushes on measures of cognitive-visual attention, physiological conditions of the heartrate, skin temperature, skin conductance and muscle tension (EMG). The findings were consistent with those obtained when the ballpoint pens and brushes were studied separately reviewed in above sections (26). These results support a cross-linguistic transfer of findings between the ball-pen and the brush as well as between the Chinese and English scripts. As for the ergonomic effects of the two instruments, we measured comfortability, controllability, ease of operation and writing speed. The ballpoint pen turned out more favorable than the brushes in all these measures.

Research on finger writing

The writing instruments in use today provide different sources of visual, tactile and kinaesthetic feedback effects associated with the writing tasks. The recent use of finger-writing as an instrument having tactile and visual feedback offers a new option for hand writing. A pilot study found that finger writing results also in improvements in attention, cognition, heart rate, blood pressure and skin temperature when compared with those changes found for the pens and brushes (27). Two more studies are reported. One is concerned with Guqin music listening as mediated by finger writing. Enhanced HRV (heartrate variability) coherence was found in post-music listening following a finger writing treatment session (28). The second study reported a case of aided finger writing treatment in successfully awakening a coma patient after two years in a state of unconsciousness (29). sum, the three instruments of the Ball-pen, the Brush and the Finger represent three broad categories of handwriting instruments: they are hard-tip ball-pen b, soft-tip brush, and the tactile-motor-fingertip, respectively. They are the handwriting tools that humans have used throughout the ages. These tools, their utilization and practice experience have contributed vastly positive and beneficial outcomes to our life, health and well-being. Below is a brief account.

Behavioral and Clinical Applications

The application of these handwriting instruments facilitates cognitive activation, physiological slowdown, emotional stability and perceptual sharpening. Successful applications of these findings have included behaviour changes in children with autism, ADHD and mental retardation; elderly disorders in Alzheimer's, cancer and stroke patients; psychosomatic diseases in hypertension and diabetes; and emotion and conduct changes in the psychiatric patients (30)In one study, we found cognitive facilitation effects of English brush handwriting being in line with those found for Chinese brush handwriting. It showed the enhanced attention and cognitive facilitation generated from the process of handwriting irrespective of the instruments or the scripts used (31). Another study showed the non-Chinese people practising Chinese brush writing exhibited similar to psycho-emotional effects as the Chinese brush practitioners.

a. Summary

Some four decades of research has demonstrated the roles and functions of handwriting as a valuable behavior system that has contributed to our intellectual development, bio-emotional activation, cognitive behavior as well as neuro-cortical facilitation. Of particular significance of this development are the neuro psychological mechanisms involved as well as its rich beneficial effects on positive behavior, health promotion, clinical treatment and rehabilitation.

b. The present study

The present study compared the ball-pen and brush and examined their respective effects on the practitioner in terms of the associated behavioral, cognitive and neural changes. The Chinese characters and English letters were used as the writing materials.

Method

a. Experimental Design and Materials

Writing tasks in brush was done with a "Ying" brush with a small size modern design with automatic ink refilling facility, while a black "Zebra Hard-Crystal N-5100" ball point pen was used. A copying mode of handwriting was adopted. For the Chinese and English scripts, a pair of stimuli consisted of one Chinese Character "zhi" which means "child", and one English character "Z" was used. Font styles in linear as well as cursive style each with upright and inverted mirror images were adopted. To add to task complexity, handwriting material was displayed in normal and disturbed order. This involved writing upright characters with top down, left to right movement for normal writing direction, and inverted mirror images of characters with bottom up, right to left, disturbed writing direction. In addition, a blank stimulus indicating no handwriting task to perform was used as the control condition. See Fig 1 for examples of the writing stimuli.

b. Participants

A total of 24 righthanded participants, 12 male and 12 female were used in this experiment. They were recruited from the University of Hong Kong as Chinese-English bilingual participants. The mean ages of the two groups were 20.5 (SD=2) and 20.5 (SD=2.4) respectively. All participants were not experienced in brush calligraphy handwriting nor with the Pinyin hand writing, And had not taken part in any similar experiments before. All participants gave informed consent before the experiment.

c. Procedure

The participant sat comfortably with his two arms resting on top of the writing platform which was placed directly in front of the projection screen where the stimulus was displayed. The distance from the eyes of the participant was kept at about 30cm to the writing plate, and about 80cm to the screen. The stimulus character, of an 8cm x 8cm square in size, was displayed on the screen at the surface level of the writing platform. Stimulus was presented randomly with ten repetitions for handwriting with brush holding in advance and the other ten repetitions for handwriting with ball-point pen holding in advance. Before starting to write, a paper sheet, on which a 2.8cm x 2.8cm square frame with a center marker "+" had been drawn and placed on the aluminium plate of the pressure transducer. The participant was then asked to position the pen or brush tip just on top of the center marker without making contact with the paper, and at the same time, pay attention to the screen for the fixation point and the stimulus character for handwriting. When the participant was ready, a 3 seconds fixation point in the form of a cross "X" was displayed on the projection screen facing the participant. Immediately after the fixation point, a stimulus character was presented, the participant needed to respond instantly when he recognized the character and then to write it on the paper within the square frame in proper proportion at his normal writing speed. Shortly after the participant had completed the handwriting task, a new piece of paper was given to him with the help of the experimenter. A new trial was initiated no less than five seconds after the presentation of the previous stimulus. EEG signals were recorded at a sampling rate of 100Hz and stored in a computer with the analog channels being connected to an EEG polygraph from the Motor (C3, C4) and the parietal (P3, P4) sites with Ag/AgCl electrodes being tested below 5K ohms. A gain of 50uv per volt for the scalp channels and 400uv per volt for the EOG channel were selected. The digitized EEG waveforms were smoothed by a digital low pass filter (Yule Walk filter) with a cut-off frequency at 45HZ. The artifact was removed by adopting the eye movement correction procedure (EMCP) with MATLAB program.

d. Data Analysis

The digitised EEG signals from the C3, C4, P3, and P4 sites of the cortex were manipulated to obtain the component amplitudes for ERPs analysis which were completed with Covariance matrices principal components Varimax analysis (PCVA). The resulting amplitude weighting coefficients (factor scores), which were generated from the SAS PCVA procedures, were analyzed by ANOVA for between subject (Sex) & within subject (Use of Different Pens, Language, Font Style & Stroke Order) analysis for the reading state (RS) and the actual writing state (AWS). Same procedure of ANOVA analysis was applied to behavioral measure on Reaction Time (RT), Writing Time (WT) and Writing Pressure (WP). The epsilon adjustment procedure for repeated measures ANOVA was applied when the degrees of freedom were more than one. In order to avoid Type I errors, conservative tests (i.e., df reduced by E=1/K) were performed. Therefore, significant levels were not directly computed from the actual degree of freedom but from the corrected ones. Results were considered significant at $P<.05$. Specific comparison with Tukey's (a) Test was used throughout the analysis.

Results

Behavioral Results

Shorter Reaction Time was found for ball-point pen than for Chinese brush. Shorter Writing Time was found for ball-point pen than for Chinese brush. And greater Writing Pressure was found for ball-point pen than for Chinese brush. See Fig 1.

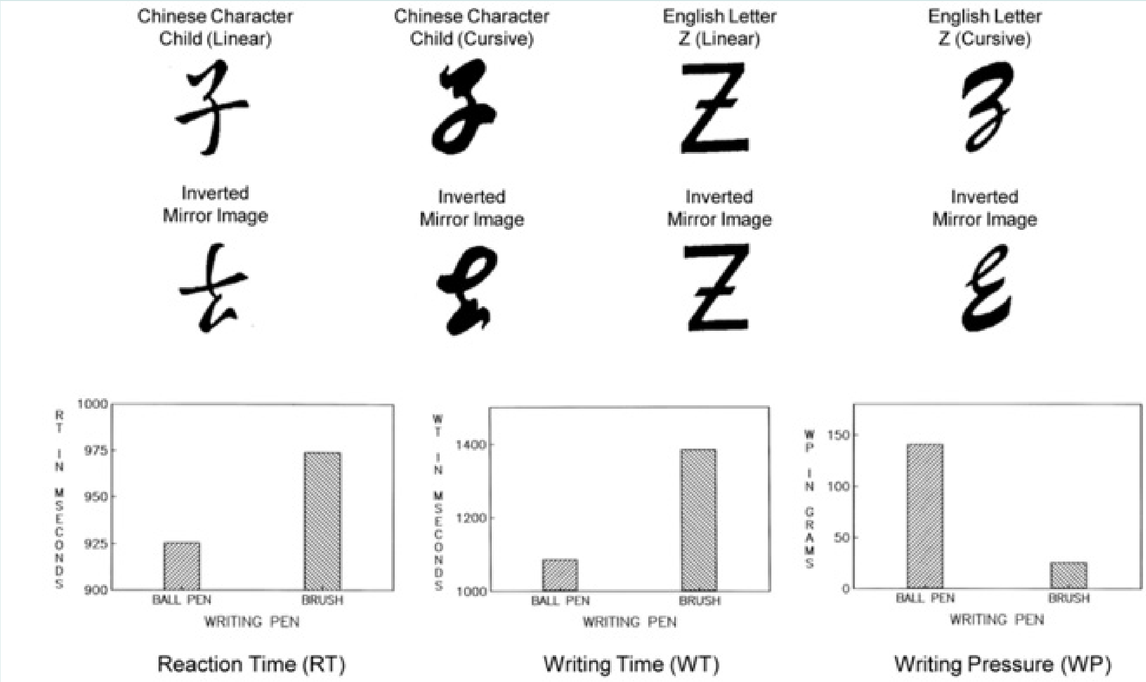

Figure 1: Examples of experimental stimuli (Chinese Character "Zih" & English Letter "Z") and task performance for writing with Ball-Pen and Brush for RT, WT & WP

a. Reaction Time for writing with Brush and Ball-Pen, the use of different writing pens revealed a shorter response time for the ball-point pen (925 msec.) than for Chinese brush (974 msec.) ($F (l, 22) = 6.119$, $P < .02$).

b. Writing time for writing with Brush and Ball-Pen, the use of different writing pens revealed a shorter writing time for ballpoint pens (1086 msec.) than for Chinese brushes (1384.9 msec.) ($F (l, 22) =19.089$，$P < .0001$).

c. Writing pressure for writing with Brush and Ball-Pen, the use of different writing pens revealed a greater writing pressure for ball-point pen (140.97 grams.) than for Chinese brush (25.55 grams.) ($F(l,22) = 113.796$, $P < .0001$).

Erp Results

During writing, Brush is active over Ball-Pen only in Parietal Cortex. See Fig 2.

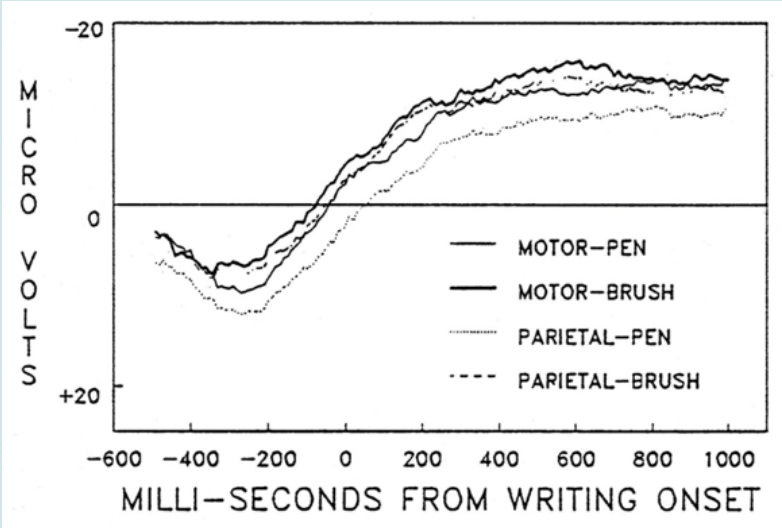

Figure 2: ERP significant results with time 0 second is the onset of writing (AWS) of the characters being displayed; during writing, Brush is active over Ball-Pen only in Parietal Cortex at N100 (F(1,22)=16.45, P<.0001).

Disscusion

We have a unique and encouraging discovery on behavioral and ERP for the neural and cognitive aspects of the use of pen in copying acts during handwriting. The Brush is active over Ball-Pen only in Parietal Cortex at N100. ERP results show that during writing, Brush is active over Ball-Pen only in Parietal Cortex at N100 due to longer reaction time and writing time of Brush over Ball-Pen. Because a 3-D effect is involved using the soft tip of the brush movement during writing actions, while the use of a Ball-Pen engages in a 2-D pen-tip motion. The brush seems to be a more activating instrument than the Ball-Pen. No significant result was found on the effect of using Chinese brush and Western ball point pen in copying the task characters during handwriting acts for ERP, Reaction Time (RT), Writing Time (WT) and Writing Pressure (WP) on Sex, Language, Style and Stroke Order. This establishes the commonness in the effects of the two different writing instruments. These results support that the use of Brush and Ball-Pen elicits distinct distributed patterns of neural activity being associated with the writing instruments irrespective of the writing scripts used, i.e. the Chinese and English writing characters. This suggests that the role of linguistic elements of character style and stroke order play insignificant roles in the handwriting process in persons with the Bilingual Brain. This also adds to the primary impact of the writing instrument instead of the visual properties of the character that is causing the cortical activation of the neural mechanism in the brain.

These effects demonstrate that skill learning of the use of Brush and Ball-Pen in the handwriting acts occurs as a result of motor control mechanisms interfacing the motor displacements relative to the spatiotemporal coherence between mind-body movements and its instrumental sensory feedbacks during the handwriting tasks. This displacement control process is mediated by neuronal detector mechanisms (Smith, & Smith, 1988) as well as a full spectrum of behavioural feedback mechanisms underlying the use of these two different writing instruments during the handwriting acts. Finger writing research dates back to an earlier framework of handwriting ergonomics . This is a new form of handwriting which is as old as human cognitive existence. It needs no paper, ink or even visual display of the characters. New forms of finger writing include finger, touch screen, wood or plastic character images or finger fluting as well. Recent mobile technology research has expanded our concept and use of finger writing or movements into touchscreen ergonomics with its cognitive and neural mechanisms correlates. The corroborative recent studies support touchscreen finger writing or painting as effective instruments have included its application for training children' self-expression , for eliciting positive, affective mindfulness, emotions, and scope of attention as well as some cognitive and neural-cortical facilitative effects on motor cortex plasticity , and memory retrieval activity (32). These are testimony to the applications of finger writing to other behavioral, cognitive and neural fields along with implications for health, therapy and rehabilitation.

Conclusion

The results suggest that the use of the Brush and Ball-Pen elicits distinct distributed activating patterns of neural mechanisms in the brain that are associated with the writing instruments, but not with the visual-spatial forms of the two character systems. These findings indicate that the two instruments in dynamic handwriting may represent two distinctive sets of neural networks in the brain; these are the visual-spatial feedback network at the right hemisphere and the somatosensory (tactile) feedback neural network at the parietal cortex. Sustained practice of handwriting with such instruments may contribute to the development of functional neural plasticity of the brain. The latest effort in developing finger as another writing instrument marks a new era and dimension of handwriting use and application. Future work with precise technology and method are recommended to verify and expand our existing knowledge and research findings. The rich and significant records of findings on handwriting have confirmed the positive and facilitative contributions of the writing tools. The specific new areas of successful application included positive health, therapy, and rehabilitation as well as behavioral change and wellbeing. The latest development and application of finger writing as the third major instrument of handwriting deserves special attention in view of its functional utility in the digital culture. The overall conclusion is this: handwriting instruments are not just for writing; they are a part of human intellectual development throughout the ages. Handwriting instruments now are a part of contemporary science and behavioral technology with immense potential to benefit mankind's health and wellbeing.

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