The Impact of Media and Background Color on Handwriting

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Abstract. Handwriting is an important issue in Taiwan's school system, and it remains to be determined if tablet computers are a suitable medium for the development of good handwriting. The primary purpose of this study is to determine whether visual and tactile instructional strategies can be used to help students improve their handwriting performance. The study recruited 31 6th grade elementary school students to hand write a short phrase on backgrounds of various colors (white, red, yellow, green and blue), both on pen and on tablet computer. Finally, a questionnaire was administered to determine emotional associations with the various background colors. Results showed that media type does have an impact on handwriting performance, with familiar media (paper) providing better results. Descriptive statistics indicate that using a red background provided the best subjective and objective performance, and consistently produced characters of better proportional size. Red was also found to have an emotional association with excitement and triggered positive emotions among the students.

Keywords: tablet computer, color, writing, handwriting, educational strategy.

1 Introduction

1.1 Research Background and Motivation

Many studies have verified that the use of tablet computers can lead to improved learning outcomes (Hulls, 2005; McClanahan, Williams, Kennedy, & Tate, 2012). Handwriting function on tablet computers is useful for handwriting practice while simultaneously allowing users to engage in visual learning strategies. In addition, many studies have examined the use of color as a learning strategy, confirming that different colors have varying impacts on learner achievement (Arnold, 1972; Fordham

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& Hayes, 2009; Iovino, Fletcher, Breitmeyer, & Foorman, 1998). Writing is a complex process requiring a focus on visual attention and physical harmony, thus this study seeks to understand the impact of tactile and visual sensory inputs on children's handwriting. We examine differences in handwriting performance using different medium for writing instruction among elementary school children, including:

1. Explore whether medium and color have an impact on children's writing performance.
2. Analyze whether specific colors can lead to improved (or degraded) writing performance.
3. Explore whether children's emotional response to or preference for different colors has an impact on student writing.

Tablet computers with capacitive touch screens are able to sense micro current, allowing users to interact with the devices using their fingers, and using one's finger to write on a tablet computer is defined as finger writing for the purposes of this study. Based on previous studies, red, blue, yellow, green and white are adopted as experimental colors, while saturation change is beyond the scope of the present study.

1.2 Educational Application of Tablet Computer Technology

Hulls (2005) reviewed studies on the use of tablet computers in classroom instruction, and found that the ability to use of colored markers, draw shapes and make annotations directly in the interface served to attract students' attention and improve understanding. Thus students who used tablet computers in class experienced better learning results.

1.3 The Impact of Color on Behavioral Performance

Different colors can have an impact on human emotion and behavior. For example, Sinclair (1988) found that students taking an accounting examination performed better when the exam was printed on blue paper than when it was printed on red paper. The changes of the subject's cognition to extend the mode in which emotion plays a role of message transmission. Specifically, the test performance enhancement associated with the use of the color blue may be due to the color transmitting a signal that indicates "relative seriousness" of the task and the "need for careful and systematic handling". The relatively poor performance associated with the color red may be due to the color transmitting a signal that indicates that the task is "more neutral and does not require systematic treatment." The transmission role played by emotion in the model has been acknowledged and extended in many studies.

The use of color has been shown to have an impact on student achievement. Therefore, this study selects the use of color as an impact factor for writing, with use of the two aforementioned media (paper and tablet computers) as the key variable. Because other studies have held that different colors have varying effects on human emotional recognition this investigation focuses on the emotional recognition corresponding to different colors.

1.4 Color/emotion Associations among Children

An understanding of how children react emotionally to culture can be used in the design of products and services for children, along with the design of learning tasks and materials. However, semantic analysis may not be applicable to an investigation of children's emotional preferences for color because, unlike adults, children may be unable to make specific semantic distinctions (Tharangie et al. 2009).

Terwogt (1995) replaced the semantic scale by asking children how they felt about six colors (yellow, blue, red, green, white and black) and listed six types of emotional adjectives in response: happy, sad, angry, frightened, surprised and annoyed. Tharangie et al. (2009) applied this modified semantic analysis method to examined the emotional response of Sri Lankan children to color. Similar to Terwogt (1995) they replaced the semantic matching scale by asking children, "What kind of feeling does this color give you" and listed 11 types of emotional adjectives happy, sad, angry, annoyed, frightened, shy, proud, delighted, kind, excited and surprised.

In addition, Boyatzis et al. (1995) observed children's emotional response to different colors. In addition to the adjectives proposed by Terwogt and Tharangie, they included strong, boring, quiet and tense. Together these studies provide a perceptual vocabulary for examining the emotions children project onto different colors.

1.5 Measuring Handwriting Standards

Currently, teachers and parents evaluate the quality of student handwriting by subjective comparison to standard forms, but legibility is still evaluated subjectively (Lam et al., 2011), which seems inadequate for such a complex handwriting process. Lam et al. (2011) suggested that accuracy is an appropriate standard for handwriting. Their study primarily focused on students with dyslexia, thus their standard of accuracy must consider common handwriting errors which they defined as follows: (1) writing outside the grid, (2) size deviates from average, (3) size deviates from standard, (4) accuracy percentage, (5) total incorrect strokes, which was further broken down as including, (a) number of missing strokes, (b) number of extraneous strokes, (c) number of mirror side errors, (d) number of inverted strokes, (e) number of incomplete strokes, (f) number of connection errors, and (g) number of stroke crossing errors.

In addition, most handwriting evaluations emphasize writing speed and cannot provide data on the actual handwriting process, which is needed to indicate root problems (Rosenblum et al., 2006). Thus Luria et al. (2010) used the length and width of letters as a standard measure for handwriting, positing that increased cognitive loading would result in handwriting exceeding the length standard.

2 Research Methods

2.1 Research Subjects

To prevent results from being impacted by inconsistencies by skill development issues and to ensure that the test subjects could easily follow the experimental

instructions, we selected 6th grade elementary school students with normal or corrected vision, and without color blindness. In total, 18 girls and 13 boys were included, and all test subjects were right handed. Two experienced elementary school teachers, aged 34, were enlisted to assist with the evaluation.

2.2 Experimental Use of Color

Based on the relevant literature, this study used white, yellow, red, blue and green backgrounds for writing tasks. Following the L*a*b range definitions devised by Lin et al. (2001) for color. To confirm that the colors used in the expeirment are consistent with human visual perception of those colors, and to ensure the consistency of color between the paper and tablet computer tasks, the researchers first tested the paper three times with a spectrophotometer, taking the average of three readings. This average value was then simulated in Adobe Photoshop on the tablet computer to render the same color as the background for the tablet.

2.3 Experimental Setup and Environment

The experimental setup primarily consisted of an iPad, paper in five different colors, black markers and video recording equipment.

To prevent distraction or unease among students, the experiments were conducted in their classrooms. To prevent environmental variation from creating color perception errors, experiments were conducted using natural light rather than fluorescent lighting, with the controlled environment color temperature between 5000K-6500K and illumination between 500LX-1000LX, while the experimental environment color temperature ranged from 5517K-6124K, and illumination ranged from 517LX-995LX. Expeirments were run at 10:00 in the morning to avoid errors caused by excessive sunlight. Measured color L*a*b* values, environmental color temperature and illumination were measured using an X-rite Eye-one Basic spectrophotometer, model i1-006. The tablet computer writing experiment was conducted using the LINE BRUSH (NAVER, Japan) program.

2.4 Writing Tasks

Table 1 shows the basic structure devised by Lam et al. (2011) for Chinese character writing tasks (independent, left-right, up-down, up-middle-down, left-middle-right, and inside-outside). This structure is used in the present study. To prevent the test subject performance from being impacted by any gap in prior learning, the writing task consisted of a single six-character phrase “提升國家藝術”. Test subjects were provided with a pre-formatted grid of six boxes in which to write the phrase (see Fig. 1).

Table 1. Basic structure

Content	提	升	國	家	藝	術
Structure	Left-right	Independent	Inside-outside	Up-down	Up-middle-down	Left-middle-right

Fig. 1. Writing screen interface: Grid configuration for writing on the tablet computer screen with different color backgrounds (white yellow, red, green and blue)

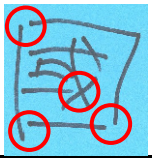
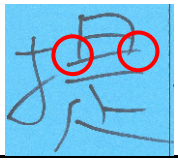
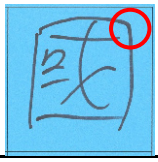
2.5 Writing Evaluation Standards

In the subjective evaluation process, the researchers and elementary school teachers first discussed evaluation criteria. The teachers then evaluated the task performance in terms of correctness and neatness, and provided a subjective evaluation score.

Each subject was identified by a serial number. Adobe Photoshop was used to render all handwriting examples as black writing on a white background. The teachers were then asked to subjectively evaluate each writing output based on a five-point Likert scale with higher scores indicating better performance.

In addition to this subjective evaluation, we referenced the accuracy evaluation criteria used by Lam et al. (2011). However, these criteria were developed for errors commonly made by dyslexic students, thus following discussion with the teachers, our researchers eliminated mirror errors, inversion errors, and broken stroke errors, and combined the missing stroke errors and extra stroke errors into a single error type. Thus, as shown in Table 2, the scoring criteria used in this study included four error types: incorrect strokes, linking errors, crossing errors, and out-of-grid errors.

Table 2. Error criteria

Linking errors	Crossing errors	Out-of-grid	Incorrect stroke
			

Also, as discussed in the literature review, handwriting performance considers handwritten information in addition to subjective evaluations. Thus, length and width are measured in cm according to the handwriting criteria devised by Luria et al. (2010).

2.6 Color Emotion Questionnaire

This study aims to determine the impact of color on the handwriting performance of children. Controlling for age and understanding of semantic analysis concepts to ensure the suitability of learner understanding and communication skills, previous relevant studies on children first selected adjectives to express common emotions, and then asked the students to match those adjectives to various colors.

Terwogt (1995), Tharangie et al. (2009) and Boyatzis et al. (1994) provided children with adjectives to describe emotions: Happy, sad, angry, annoyed, frightened, shy, proud, delighted kind, excited, surprised, strong, boring, calm and nervous. The questionnaire asked subjects to pair these adjectives to the colors white, yellow, red, blue and green.

2.7 Experimental Procedure

The researchers first explained the experimental process and asked the participants to write a single six-character phrase in a six-box grid on five types of colored paper and on a tablet computer, thus each subject wrote the same phrase ten times. Mistakes could not be corrected or erased.

Step 1: Participants were given five minutes to write the phrase "提升國家藝術" on five sheets of colored paper (white, red, yellow, green and blue) presented in a random order.

Step 2: The participants were given five minutes to write the same phrase on a tablet computer five times, each time with a different background color (white, red, yellow, green and blue). Due to the application restrictions, when the subject completed writing on one color background, the researcher assisted in changing the background to another color selected at random. While the total time for each step was five minutes, participants were free to use that time as they saw fit for each sub-task.

Step 3: Subjects answered the color emotion questionnaire, matching emotion adjectives to each of the test colors (white, yellow, red, green and blue).

3 Results

3.1 Impact of Media and Color on Handwriting Performance

Through the teachers' subjective evaluation, objective criteria, and length and width measurements, we conducted MANOVA analysis for media x color x writing performance. Descriptive statistics were also used to describe the characteristics of data, and impact trends for observable factors.

3.2 Impact of Media and Color on Subjective Ratings

In the teachers' subject evaluation of the students' handwriting, use of different media had a significant impact ($F>1$, $P<0.05$). However, the interactive relationship between

color and color with media does not meet the conditions of $F>1$, $P<0.05$, and is thus not statistically significant.

Descriptive statistics show that paper tests had an average subjective score of 3.14, as opposed to 2.77 for tablet computers. In addition, the average scores for the five colors indicate that red had the best performance for both paper and tablet computers, while that for green was lowest.

3.3 Impact of Media and Color on Objective Evaluations

The total number of handwriting errors (including incorrect strokes, linking errors, crossing errors and out-of-grid errors) was statistically positive for both media and color ($F>1$, $P<0.05$).

From the descriptive statistics, the average total number of errors for the paper test was 3.92, as opposed to 11.77 for the tablet computer test. In addition, red backgrounds produced the lowest average total errors (i.e., best performance) for both the tablet computer and paper tests, while blue produced the highest.

Tukey's post hoc test was used to determine that red and blue have significant impact on the objective assessment for total errors (including incorrect strokes, linking errors, crossing errors and out-of-grid errors), with a P value of 0.021.

The objective evaluation of total errors applies MANOVA analysis to errors grouped under categories of incorrect strokes, linking errors, crossing errors and out-of-grid errors to find that media is significant for all error types, but that color is only significant for linking errors.

3.4 Impact of Media and Color on Length and Width

Luria et al. (2010) suggested that increased psychological loading would cause subjects to write characters with increased length (i.e., from top to bottom). Thus, standard criteria were set for the length and width of handwritten characters. We found media to have a statistically significant impact on length and width ($F>1$, $P<0.05$), while color did not ($F>1$, $P<0.05$).

3.5 Impact of Interactive Operation

Interactive operations were found to not be significant, indicating a lack of interactive operation between media and color. Thus, for the subjects, color did not arouse different emotional responses between the tablet computer and paper, suggesting that the experimental design for this research was successful in reproducing the exact same color for the task backgrounds in both media.

3.6 Color Emotions

The chi-square test was used to determine the independence of a child's emotional response to color (i.e., whether the child can distinguish emotional responses to

colors), with a significance level of 0.000. Thus, descriptive statistics could be used to explore the children's emotional tendencies for the various colors. We found that children associated red with "exciting", white with "calm", blue with "delighted" "calm" and "friendly", and green with "delighted" and "friendly", while yellow had no significant emotional associations.

4 Discussion

This section uses the experimental analysis results and related literature to explore potential causes for the experimental results and provide recommendations.

4.1 Media Impact on Handwriting Performance

The analysis shows that different writing media has an impact on handwriting performance. Writing on paper earned higher subjective scores with fewer errors, and the characters tended to be shorter and narrower. A possible reason for the improved performance on paper is that test subjects were more familiar with writing on paper. This is supported by the better control over character length and width – the characters written on the paper test were significantly smaller than those on the tablet computer test because subjects were accustomed to writing characters of a certain size. Using pencil and paper, students were less susceptible to the influence of color, or perhaps due to increased writing automation, the task required less attention and control, and because their writing actions were more reliant on habit (Tucha et al., 2006) the impact of color was reduced.

4.2 Impact of Color on Writing Performance

The Tukey test showed red and blue had a significant impact on the objective evaluation of total error instances. Descriptive statistics indicate that red had the lowest average number of errors on the tablet computer (average: 9.35) and on paper (average: 2.48), indicating better performance, while blue had the highest average number of errors for both the tablet computer (average: 13.97) and paper (average: 4.74). Although color was not significant for the height and width of the characters, descriptive statistics indicate that, compared to other colors, red backgrounds produced larger characters (average height: 36.37; average width: 34.27), while blue produced smaller ones (average height: 35.84; average width: 33.36).

4.3 Impact of Specific Colors on Writing Performance

Although color did not have a significant impact on subjective scores, descriptive statistics indicate that, compared to other colors red resulted in higher subjective scores for both the tablet computer (average: 2.92) and paper (average: 3.18) and lower numbers of errors (including incorrect strokes, linking errors, crossing errors and out-of-grid errors), while green had lower scores for both the tablet computer

(average: 2.58) and paper (average: 3.08). Red also produced larger character length and width values.

4.4 Impact of Color Emotion on Handwriting

Most test subjects were found to positively associate red with "excited", unlike Tharangie's (2009) Sri Lankan children who associated it with "frightened", and this may have contributed to their improved performance with red backgrounds. In addition, statistically the subjects were found to associate primary colors with positive emotions (happy, friendly, excited and calm), indicating that color projection was relatively positive. Blue and green had similar emotional responses (happy, pleasant). Subjective score results for green were relatively low, while blue had lower total errors, and smaller heights and widths.

4.5 Difference between Subjective Scores and Objective Evaluation

The different media produced different results for subjective and objective evaluations due to the use of scores in the subjective evaluation: good performance was scored 4 or 5, while flawed characters were scored 2 or 3, and poor performance was scored as 1.

While the subjective and objective evaluation results may vary, bivariate correlation analysis found the two evaluations to be significantly and negatively correlated (Pearson correlation coefficient 0.556, P=0.000) because better samples of handwriting performance, which scored higher in the subjective assessment typically, had fewer errors according to the objective criteria. From this, we can see that the subjective and objective evaluations are still consistent, but because the objective assessment calculates the number of errors, it is better able to analyze the types and trends of handwriting errors.

4.6 Conclusions

The key goals and results of this study are as follows:

1. Explore whether medium and color have an impact on children's writing performance.
    a. Media was found to have an impact on handwriting in terms of subjective scores, objective evaluations of total error instances, and character length and width. Paper-based tasks were found to produce smaller and more proportional characters than tablet-based tasks.
    b. Color was found to have an impact on the objective evaluation of total error instances.
    c. No interaction was found for color and media.
2. Analyze whether specific colors can lead to improved (or degraded) writing performance: using red as the background color produced higher subjective scores

and fewer total errors, along with larger, proportional characters. Results for the paper and tablet-based tests were similar.
3. Explore whether children's emotional response to or preference for different colors has an impact on student writing: color preference was found to be correlated with subjective scores and character length and width. Red was found to be associated with positive emotional adjectives and the use of red backgrounds produced improved performance.

4.7 Contributions and Suggestions

There is a trend towards increased use of tablet computers in schools. Unlike previous studies which conducted experiments using paper-based tasks alone, this study includes an investigation of writing tasks on new media forms and uses descriptive statistics to determine that red backgrounds have a positive impact on both tablet and paper-based writing tasks, both in terms of subjective scores and objective evaluation total error instances. The use of red also corresponds with greater length and width. Thus, the results of this study indicate that red consistently produces better results.

In addition, when students are less familiar with the writing media, their writing is less automatic and they are unable to rely on muscle memory. Thus the use of less familiar writing media can easily impact the writing process, and thus they can be used as tools to assess handwriting capability or fine motor skills.

Children were found to perform less well on writing tasks on tablet computers than on paper. Recording stroke order tablet computers provides useful information in understanding the writing errors, which is required for optimal performance. However, because color impacts handwriting performance, designers should consider incorporating red backgrounds into products, services, learning strategies and educational software for children. Designers also need to consider children's color preferences and emotional associations in that using a color with positive associations may help to improve learning outcomes.

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