ORIGINAL ARTICLE

Effect of Colored Overlays on Reading Comfort in People with and without Meares-Irlen Syndrome

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Abstract: People with Meares-Irlen syndrome (MIS) perceive visual distortions and abnormal brightness in text. Translucent colored overlays may alleviate these symptoms, making reading more comfortable. We examined various colors' effect on reading comfort, and whether colored overlays affect reading in Japanese participants with and without possible MIS. Participants read Japanese syllabary (Hiragana) and English alphabets with ten colored overlays (purple, rose, peach, orange, yellow, green, light blue, blue, blue-gray, and gray), and without overlay. After reading the texts, participants ranked each overlay color's reading comfort. In both the Hiragana and English alphabet conditions, participants with possible MIS ranked the blue-gray and light blue overlays highly, and normal controls ranked blue-gray, gray, green, and light blue highly. These results suggest that bluish-colored overlays make reading more comfortable in people with and without MIS.

Keywords: *Visual perception, Color, Reading*

1. INTRODUCTION

Letters, existing everywhere in various cultures, convey conceptual and affective information. We visually perceive letters, individually and as words and sentences, and are able to know the meaning and to experience affective states. Since reading has a fundamental role in our living environment, Kansei (affective) engineering and psychophysical studies have sought to investigate legibility (e.g., [1]) and beauty (e.g., [2]) of letters. On the other hand, some individuals have an impaired reading due to their altered visual processing, for instance, Meares-Irlen syndrome (MIS). Thus, studies should clarify the visual perception in people with and without impaired reading and develop effective interventions for their reading, in order to pursuit comfortable living environment including text.

1.1 Meares-Irlen Syndrome

People with MIS experience visual distortions, eyestrain, and headaches when reading texts and observing striped patterns [3-5]. Such distortions include blurriness, transposition, reversal, shimmer, and glare. These abnormal perceptions affect up to 46% of individuals with dyslexia, reading problems, and learning difficulties [6] and 15% of individuals without such difficulties [7]. Further, MIS is associated with migraine [8], autism spectrum disorder [9], and chronic fatigue syndrome [10].

MIS is thought to originate in low-level visual processing systems. Visual stimuli, such as letters and colors,

are transmitted from the retina to the occipital visual cortex through two pathways: the magnocellular pathway (high temporal resolution) and the parvocellular pathway (relatively low temporal resolution) [11, 12]. The magnocellular and parvocellular pathways then proceed to higher processing, branching onto the dorsal pathway projecting onto the parietal cortex, and the ventral pathway projecting onto the inferior temporal cortex, respectively [13]. Regarding letter recognition, it has been suggested that phonograms (e.g., the English alphabet and Japanese syllabary) and morphograms (e.g., Chinese characters) are distinctively processed in the magnocellular-dorsal and parvocellular-ventral pathways, respectively [14-17].

Studies have proposed two mechanisms underlying MIS in the visual system. First, visual stimulation may attenuate inhibitory mechanisms in the hyperexcitable visual cortex, resulting in visual distortions such as blurriness and glare [18, 19]. Second, malfunction in the high-temporal resolution magnocellular pathway may cause failure to inhibit anomalous visual traces induced by saccadic eye movements, resulting in visual distortions [17, 20, 21].

1.2 Effect of Color on Meares-Irlen Syndrome

Translucent colored overlays on text may reduce MIS symptoms. This intervention has been found to alleviate visual distortions and discomfort, and improve reading accuracy [4, 22-24]. Further, prolonged use of these overlays may enhance symptom improvement [25, 26].

Importantly, a study using a double-blind method demonstrated these benefits, and excluded the placebo effect [23].

Since red light has been shown to inhibit the activity of the magnocellular system [27, 28], it may be assumed that colored overlays that exclude long-wavelength light (i.e., red) facilitate the magnocellular pathway's function and consequently alleviate MIS [29]. Indeed, a previous study has suggested that blue and bluish-green overlays (which exclude long-wavelength light) facilitate reading [30]; however, the most beneficial overlay color has been found to vary among individuals [5, 8, 22, 23, 31]. While the source of between-individual variation remains unclear [32], studies have investigated which colors are most beneficial to patients with MIS. Kumagai [33] reported that bluish- and greenish-colored overlays tend to facilitate reading and visual search in dyslexic students. Afterward, Kumagai [34] reported a preference for blue overlays in people with MIS. People without MIS have also been reported to prefer reading with bluish overlays [35, 36]. These results suggest that bluish or greenish overlays may facilitate reading in people with and without MIS; however, this is uncertain as these studies [34-36] used a descriptive method and did not statistically test preferences for colors. Further, these studies' results cannot establish if there are differences between people with and without MIS regarding the effect of colored overlays on reading.

Although the effect of overlays has been examined, few studies have examined the effect of text, particularly letter type (e.g., English alphabet versus Hiragana), on colored overlays' facilitation of reading. A previous study has reported, however, that Italian native speakers who are able to speak Japanese as a second language show slower reaction times to Hiragana than that to English alphabet, because of varying levels of processing proficiency in these languages [37]. The effects of colored overlay on reading may therefore be assumed to vary between native and second-language text.

1.3 Present Study

We had three purposes. First, we examined which color of overlay is more comfortable to read using a normalized ranking method [38], which transforms ordinal data (i.e., a ranking) into approximate interval data (i.e., a normalized score), allowing statistical tests with multiple comparison between conditions. This approach extended previous findings [34-36], which have suggested a preference for specific colored overlays in people with MIS, but lacked statistical methods.

Second, we examined differences in the effect of colored overlays on reading comfort between individuals with possible MIS and normal controls, using a between-participants factorial design. This approach extended previous findings that investigated the effect of colored overlays on reading in either people with MIS or normal controls [34, 36].

Finally, we examined differences between the effects of colored overlays on reading native and non-native language in Japan (i.e., Hiragana versus English alphabet). This approach may provide a new perspective on research examining reading comfort and its relationship with color in people with MIS [34-36] and dyslexia [31, 33]. Previous research has not compared different languages regarding the effects of colored overlays on reading comfort.

2. METHODS

2.1 Participants

Ten adults with possible MIS (eight females; mean age 24.57 ± 7.18 years) and twenty-five adults without MIS (twelve females; mean age 22.76 ± 2.30 years) participated in the experiment as the MIS and control groups, respectively. We separated the participants into the MIS and control groups using a questionnaire, which was based on the Short Self-Test for Irlen Syndrome [4], and a post-hoc non-structured interview. The questionnaire was comprised of 14 questions concerning difficulty in reading and somatic issues, for instance, "Do you blink or squint?" and "Do you get headaches when you read?" Participants answered each question by selecting one of four responses: "never," "occasionally," "often," and "almost always." The response "almost always" scored 2, "often" scored 1, and other responses scored 0. The summed score for the 14 questions served as an MIS index. We interviewed participants with an MIS index above six to confirm they had MIS, specifically, perceived visual distortion, eyestrain, and headaches in daily life especially when reading. Nevertheless, as our screening method may have been quasi-valid, we were constrained to refer to participants in the MIS group as *possible* MIS cases.

All participants were Japanese native speakers and had normal or corrected-to-normal visual acuity with no visual deficits, such as color blindness. Written informed consent was obtained from each participant. This study was approved by the ethical committee of the Graduate School of Engineering, Chiba University, and was conducted in accordance with the principles of the Declaration of Helsinki.

2.2 Stimuli

Meaningless strings of either 144 Hiragana letters (i.e., Japanese syllabary) or 216 capitalized English alphabet letters in MS Gothic font, in 33.75-point type, were printed in black on matte white paper measuring 210 × 297 mm, such that strings formed a square of 150 × 150 mm at the center of the paper (Figure 1). Although the strings were randomly generated, some letters occurred repeatedly in single strings, as Hiragana and the English alphabet consist of forty-six and twenty-six letters, respectively.

We used a set of translucent matte overlays with ten colors (referred to as “colored overlays” in this study) (Irlen Institute, CA, USA) that measured 230 × 300 mm (Figure 1). Colors consisted of purple (Munsell hue, value/chroma: 5P 5/10), peach (2.5YR 7/8), rose (5R 7/8), orange (7.5YR 7/12), yellow (10Y 8/8), green (2.5G 8/8), light blue (7.5BG 7/8), blue (10B 5/12), blue-gray (7.5B 8/2), and gray (10Y 6/1). The authors measured the overlays’ Munsell values using visual colorimetry.

Each of the ten overlays was superimposed and fastened on the sheets of paper bearing strings of letters. A stimulus without an overlay was also prepared. Finally, we obtained twenty-two experimental stimuli (two language conditions: Hiragana or English alphabet; eleven overlay conditions: ten colored overlays or the absence of overlay). The combination of overlays with paper sheets was randomized.

2.3 Procedures

The experiment was conducted individually in a well-lit room (illuminance approximately 400 lx, measured at participant’s position). Participants sat at a desk without any constraint on viewing distance.

Eleven stimuli with either Hiragana or English alphabet were arranged on the desk, which was wide enough to prevent the stimuli overlapping. Initially, in order to familiarize the participants with reading the stimuli, participants performed a visual search task, in which participants were orally instructed to search a stimulus for two randomly selected letters (e.g., “き” (*ki*) and “な” (*na*), or “E” and “Q”). Stimuli were presented one by one in a randomized order. Participants responded orally when they located the target letters. No feedback was given to participants’ response.

Following the visual search task, participants evaluated the comfort of reading each stimulus using a normalized ranking method [38]. Participants were allowed to pick up and rearrange the eleven stimuli on the desk. Participants then ranked each stimulus’ reading comfort, and filled in a form. There was no time constraint on evaluation.

The abovementioned procedures were repeated in the other language condition. The order of language conditions was counterbalanced across participants.

Figure 1: Meaningless Hiragana (Japanese syllabary) and English alphabet strings, and colored overlays

2.4 Data Analysis

Each participant's ranking of each stimulus was obtained and converted to a normalized score (cf. [38, 39]). An analysis of variance (ANOVA) with two within factors (overlay color: 10 colors, absence of overlay; language: Hiragana, English alphabet) and a between factor (MIS: MIS group, control group) was performed on stimuli's normalized ranking scores. When the sphericity assumption of the ANOVA was violated, Huynh-Feldt correction was applied to the degrees of freedom. Bonferroni correction was used for multiple comparisons.

The significance level was set at $p < .05$. Effect size was reported as partial eta squared (η_p^2). Statistical analyses were performed using SPSS 17.0 (IBM Corp., NY, USA).

3. RESULTS

Figure 2 presents results from the MIS and control groups under Hiragana- and English alphabet-stimulus conditions. Normalized scores were calculated at 1.59, 1.06, 0.73, 0.46, 0.22, 0.00, -0.22, -0.46, -0.73, -1.06, and -1.59 corresponding to the first to last rankings,

Figure 2: Normalized ranking scores for stimuli with and without colored overlays in the MIS and control groups under Hiragana and English alphabet conditions (square brackets indicate significant differences, * $p < .05$, ** $p < .01$)

respectively. The ANOVA's results indicated a significant main effect of overlay color ($F(10, 187.23)=7.48, p<.01, \eta^2_p=.19$). However, overlay color did not interact with MIS or language, or with both MIS and language (overlay color and MIS: $F(10, 330)=1.17, p=.31, \eta^2_p=.03$; overlay color and language: $F(10, 298.10)=0.55, p=.84, \eta^2_p=.02$; overlay color, MIS, and language: $F(10, 330)=0.36, p=.97, \eta^2_p=.01$).

In the MIS group, the light blue and blue-gray overlays were found to considerably increase Hiragana and English alphabet reading comfort. In the Hiragana condition, the light blue overlay increased reading comfort significantly more than the seven conditions below peach did ($p<.01$). The blue-gray and green overlays increased reading comfort in Hiragana significantly more than the two conditions below blue did ($ps<.05$). By contrast, regarding English alphabet, the light blue and blue-gray overlays increased reading comfort significantly more than the five conditions below rose did (light blue and rose, $p<.01$; blue-gray and rose, $p<.05$). Orange, green, and peach overlays increased reading comfort in the English alphabet condition significantly more than the three conditions below purple did ($ps<.05$). Absent-overlay conditions were ranked lowest in both the Hiragana and English alphabet conditions.

In the control group, blue-gray, gray, green, and light blue overlays were found to considerably increase reading comfort in both the Hiragana and English alphabet conditions, similarly to the MIS group. Blue-gray, gray, and green overlays increased reading comfort in Hiragana and English alphabet significantly more than the seven conditions below peach did ($ps<.05$). Specifically, blue-gray increased reading comfort significantly more than the colors ranked third did in the Hiragana and English alphabet conditions (Hiragana: blue-gray and green, $p<.05$; alphabet: blue-gray and light blue, $p<.05$).

4. DISCUSSION

We examined which color of overlay may increase text-reading comfort in people with and without possible MIS, and how text type affects colored overlays' effect. Results provided three main findings.

First, we showed that bluish-colored overlays increased reading comfort in participants with and without possible MIS. Specifically, blue-gray and light blue considerably increased reading comfort in the MIS group, whereas blue-gray, light blue, green, and gray did so in the control group. Our findings, which used statistical tests with multiple comparisons, support and extend previous

findings suggesting the benefit of bluish-colored overlays both in patients with MIS [34] and in healthy individuals [35,36]. Preferences for bluish-colored overlays, which exclude long-wavelength light (i.e., red) may also be consistent with the magnocellular deficit theory of MIS, assuming that red light inhibits the activity of the magnocellular pathway and consequently distorts visual perception [17,20,21,29]. The blue overlay was ranked lower in both the MIS and control groups, however. We consider that this may be because the most saturated blue overlay reduced MIS' effect on reading, which is due to excess color information [40]. Confounding of overlay colors' saturation (perhaps also brightness) may hence constitute a limitation of this study, as we followed overlays usage practices developed in interventions [4]. Further research should directly examine the effect of overlay colors' saturation on reading comfort.

Second, both the MIS and control groups ranked bluish colors highly, suggesting few differences in colored overlays' effect on reading between people with and without MIS. This is consistent with previous studies that have argued that bluish-colored overlays facilitate reading in patients with MIS [29,30,34] and healthy individuals [33,35,36,41]. One notable difference was that the MIS group ranked blue-gray and light blue highest, whereas the control group ranked only blue-gray highest. This suggests that reading comfort may be best promoted in patients with MIS by using bluish colors. Importantly, our results also suggest that, in the control group, at least the four highest ranked colors (blue-gray, light blue, green, and gray) increased reading comfort more than in the absent-overlay condition. This implies that colored overlays, which were originally developed for patients with MIS, may also facilitate reading in normal individuals; however, interpretive care should be taken, as this study examined individuals with possible MIS. Future studies should recruit individuals with MIS diagnosed based on clinical assessment by qualified psychologists, and seek to replicate the present findings.

Finally, we did not find differences in the effects of colored overlays on reading letters in one's native and second language (i.e., Hiragana and English alphabet in Japan). This suggests that the experience of reading or observing letters does not mediate the effect of colored overlays. Although the lack of a language effect was our null hypothesis, two explanations may be offered. First, while MIS is thought to stem from low-level color-processing visual systems, which may affect reading [18,19], higher-level systems importantly affect perception and recognition of Hiragana and English

alphabet (i.e., phonograms) [14-17]. It is likely that overlay colors minimally affect processing in high-level visual systems, and therefore that no differential effect between languages exists. Second, this result may be explained by the similar morphological properties of Hiragana and the English alphabet, which consist of somewhat simple patterns. Further research should examine the effect of colored overlays on more complex letters, such as Kanji (Chinese characters which are also used in Japan), and visually complex words forming striped patterns (e.g., “mum”). Indeed, Kanji and several specific alphabet chunks have been reported to diminish reading efficiency [42] and induce visual stress and discomfort, effects that often accompany MIS [43].

5. CONCLUSION

Colored overlays, especially bluish colors, may make reading more comfortable in people with and without MIS; this effect is not likely to be influenced by differences between Hiragana and the English alphabet. Further research examining multidimensional reading performance (e.g., reading speed [44,45] and comprehension [22]) in people with and without MIS may contribute to the development of effective therapy for MIS and education by using color. Our findings may also inform future Kansei (affective) engineering studies on designing letters, color, and their interaction, promoting a comfortable environment.

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