# Effect of background colours in digital material on comprehension

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# Effect of background colours in digital material on comprehension

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This study examines the impact of digital material background colours on comprehension and preference in higher education, comparing native and non-native English speakers. Utilising a mixed-method experimental design, the study explored how eight colours influenced comprehension performance, response times, and colour preferences among 40 participants. Results indicated no significant effect of background colour on comprehension metrics, with both native and non-native groups showing similar performance across all colour conditions (within-subjects ANOVAs $p > 0.05$). Some evidence for the effectiveness of different coloured backgrounds for different participants was found. In addition, non-native speakers exhibited lower correction rates and longer response times, highlighting the challenges faced by this group in digital learning environments in which English is the primary language instead of their mother tongue. Preferences for certain colours varied significantly between groups, with native speakers favouring blue and purple, and non-native speakers showing a distinct preference for yellow and blue (between-subjects ANOVAs $p < 0.05$). These findings suggest that while colour does not affect comprehension directly, it does influence learner satisfaction and engagement. The study underscores the importance of considering aesthetic elements like colour in the design of digital educational materials to enhance learner experience and engagement. This research contributes to the field of educational media design, advocating for a learner-centred approach that accommodates diverse linguistic and cultural backgrounds in digital learning environments.

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## Introduction

The digitisation of education has transformed the traditional classroom, creating a digital, networked, and visual learning environment. This evolution has been taking place for several decades. In 2001, Charles Vest, the President of MIT, revealed the institution's plan to make the course materials from almost every undergraduate and graduate program available online globally via the OpenCourseWare (OCW) initiative [1]. Initially, OCW was conceived as a mere concept—a bold assumption based on informed judgment that it was the correct step forward and would contribute to educational advancement [2]. This learning mode was accelerated by the COVID-19 pandemic, and resources such as OCW have become even more valuable, resulting in a 60% increase in website visits from all over the world during the peak quarantine months of April-May 2020; eLearning tools are now ubiquitous in education [3-4]. As educators and students navigate this new area, the design of digital instructional materials, particularly the use of colour, has come under scrutiny for its potential to enhance learning comprehension.

The cognitive theory of multimedia learning provides a robust framework for this investigation, suggesting that information processed through multiple channels enhances learning efficiency [5]. Colour's role in educational materials, while widespread, remains an area of contention regarding its effectiveness in improving student achievement [6]. Several studies have sought to clarify this by examining how colour or combinations thereof can aid in recalling information and understanding text-based materials [7-8]. Attention and memory are crucial cognitive processes affected by colour. The relationship between colour and cognitive learning abilities has been demonstrated in various domains, including education, marketing, and even sportswear [9-12]. This study focuses on four key areas where colour's impact on cognitive functions is significant: attention, memory, readability, and the learning environment.

Attention, a selective cognitive process, is crucial for learning. The influence of colour on attention has been substantiated by Engelbrecht [13], who notes that colour can elicit both immediate and lasting psychological responses. For instance, Farley & Grant [14] demonstrated that colour in multimedia presentations could enhance attention and memory retention. Kennedy [15] furthered this understanding by showing that colour stimulation in learning environments not only improves attention but also academic performance. These findings underscore the role of colour in creating engaging learning experiences, which, according to Verghese [16], aligns with signal detection theory's assertion that the human brain seeks to organise visual information efficiently, suggesting an intrinsic link between colour, attention, and cognitive load management.

Memory's role in the learning process is significantly influenced by colour. Studies have shown that colour aids in the encoding, retention, and retrieval of information, with certain hues enhancing concentration levels and, subsequently, memory storage [17-19]. Naz and Helen [20] found that colours evoke specific emotions, which in turn can affect memory retention. Similarly, Greene *et al.* [21] concluded that warm colours like yellow, red, and orange are more impactful on attention and memory than cooler colours, suggesting a direct correlation between colour-induced emotional arousal and enhanced memory capabilities.

Readability is a precondition in the design of digital educational materials, with colour playing a critical role. While early research focused on the readability of text on screens under various technological limitations, more recent studies have highlighted the importance of colour contrast in enhancing text legibility [22-23]. High contrast between text and background has been shown to improve readability, which directly influences comprehension and memory retention. Hall and Hanna [24] found that black text on a white background offers the highest readability due to its strong contrast, yet the impact of colour contrast on memory remains a subject of ongoing investigation.

The design of the learning environment, including the use of colour, significantly impacts student behaviour and performance. Colour evokes profound psychological and physiological responses, influencing mood, mental clarity, and energy levels [13, 25]. This study extends these insights to the digital realm, examining how colour in virtual learning spaces affects learner engagement and comprehension. Bingham and Conner [26] define learning as a transformative process based on input, process, and reflection. The process of this definition is a consequence of ongoing interactions between the learner's prior knowledge and the complex social environment in which the learner occurs. It indicates that the physical and social environment are important variables in the learning process. The interaction between environmental stimuli and cognitive processing highlights the potential of colour to enhance the learning experience, making it a vital element in the design of digital educational materials.

This study aims to explore the impact of colour in digital learning materials on students' comprehension abilities and to identify the most effective colour background for learning outcomes.

Drawing on cognitive psychology, this study is guided by the hypothesis that learners' comprehension of text-based information varies with the background colour (hue) of the learning material. The work may contribute to the development of more effective digital learning environments, thereby enriching the educational experience for learners worldwide.

## Methods

### *Experimental material preparation*

In this study text was displayed on various coloured backgrounds in a digital environment. Following Pettersson's [27] principles for screen information design, the chosen fonts for the text were Verdana and Times New Roman, optimised for screen legibility. Font sizes were set according to Rambally [28], with 24 points (typically 32px) body size for text, 30 points (typically 40px) for headings in Verdana, and 18 points (typically 24px) for footnotes in serif font Times New Roman.

Eight different background colours were used; six chromatic colours (red, orange, yellow, green, blue, and purple) were selected alongside a grey reference used as a control group, in line with Camgöz *et al.* [29]. If we measure hue in the HSV hue circle, then the hue angles of the chromatic backgrounds were 0° (red), 30° (orange), 60° (yellow), 120° (green), 240° (blue) and 270° (purple). The study incorporates black as an additional colour due to its frequent use in digital teaching materials and modern digital device preferences [30]. Generally, the colour of the text was black; however, in the case of the black background the colour of the text was grey. However, in all eight conditions the contrast ratio between text and background was very similar (see Table 1 for further details).

| Colour name | Colour sample | H | S | V | R | G | B | contrast ratio |
|---|---|---|---|---|---|---|---|---|
| Reference grey | | 0 | 0% | 60% | 153 | 153 | 153 | 7.37 |
| Red | | 0 | 60% | 100% | 255 | 102 | 102 | 7.34 |
| Orange | | 30 | 100% | 94% | 240 | 120 | 0 | 7.39 |
| Yellow | | 60 | 100% | 62% | 158 | 158 | 0 | 7.34 |
| Green | | 120 | 100% | 70% | 0 | 178 | 0 | 7.37 |
| Blue | | 240 | 45% | 100% | 140 | 140 | 255 | 7.31 |
| Purple | | 270 | 52% | 100% | 189 | 122 | 255 | 7.39 |
| Black | | 0 | 0% | 0% | 0 | 0 | 0 | --- |

*Table 1: The sRGB colour coordinates of the eight background colours. The HSV values and contrast ratios are also shown. (Note: The colour names indicate the hue value of the colours and ensure that all combinations of foreground and background colours have their contrast controlled around 7.3. The saturation and brightness will need some tweaking, so some of these colours may not represent the name)*

Black text was selected in most cases because it has been found that against different colour backgrounds, black text will be more readable compared to other colours [31]. It is important to ensure that the contrast ratio is very similar in all cases because contrast likely affects readability [32].

### *Luminance contrast between background and foreground (text) colours*

The luminance contrast between the background and critical visual cues is essential to ensuring the readability of learning materials, and some researchers suggest that this contrast should be fixed between the 3:1 to 7:1 threshold set by the W3C specifications [33-35]. Relative luminance (L) can be calculated from a linear combination of RGB values using Equation 1 [35].

$$L = 0.2126R + 0.7152G + 0.0722B \tag{1}$$

The contrast ratio (CR) between the relative luminance of the text and background can be calculated using Equation 2:

$$CR = (L1+0.05)/(L2+0.05) \tag{2}$$

where L1 is the relative luminance of the lighter of the foreground and background colours, and L2 is the relative luminance of the darker of the foreground and background colours. Based on Eqn 2 CR values will be 1 or higher. The ANSI/HFS 100-1988 standard [33-34] requires that the contribution from ambient light be considered when calculating L1 and L2. This methodological choice is rooted in the WCAG 2.1 Understanding Docs [36], reflecting the necessity for a minimum acceptable contrast to accommodate various viewer sensitivities.

### *Participant criteria*

In this experiment, participants were selected based on the following three criteria: (1) having a normal colour vision, (2) currently having or having obtained a degree in higher education, and (3) having experience in online learning education to offer relevant insights in the subsequent questionnaire. Based on the above screening conditions, 60 participants were recruited for this experiment, with a balanced mix of participants' gender and primary language.

The inclusion criteria mandated normal colour vision, verified through the online Ishihara Colour Blindness Test (ICBT). This approach aligns with recent findings by Marey *et al*. [37] and Gjærde *et al*. [38], demonstrating the feasibility of online colour vision assessments for ensuring participant eligibility.

Some of the participants (20) participated in the experiment online and this means that it is difficult to control their viewing environment and the display that they used. For this reason, the 20 online participants were removed from most of the analysis in this paper so the final number of participants was 40. These 40 participants undertook the experiment in a laboratory setting with consistent ambient lighting and display. Table 2 shows a summary of the 40 participants whose data were used. The average age of the 40 participants who took part in the experimental part of the study was 28.7 (19–56 years old).

| Gender | Native English group | Non-native English group | Total |
|---|---|---|---|
| Female | 12 | 9 | 21 |
| Male | 12 | 7 | 19 |
| Total | 24 | 16 | 40 |

*Table 2: The distribution of the 40 participants (offline and online).*

### *Online learning experience and colour preference questionnaire*

An online questionnaire evaluated participants' online learning experiences, colour preferences, and readability and legibility of digital learning materials. The questionnaire took about 10 minutes to complete and consisted of 29 questions. As part of this participants were presented with text on 8 coloured backgrounds and were asked to subjectively score each of these for (1) preference, (2) readability and (3) legibility. Following the questionnaire, participants undertook the main experimental study.

### *Comprehensive test materials*

To assess comprehension, the study employed a set of questions ("Comprehension test - word changes questions") that were designed to test verbal skills and the ability to understand textual information [39]. This method avoided the limitations associated with single-choice and multiple-choice questions, requiring participants to reorganise words to correct sentences. Participants' comprehension was measured based on the time taken and the correctness of responses. Correctness of response (comprehension) was measured by the number of words moved (see Figure 1) and whether the adjusted sentence was correct according to a method provided with the test [39]; correctness was expressed as a fraction (where 1 indicates that all of the words were moved to the correction positions).

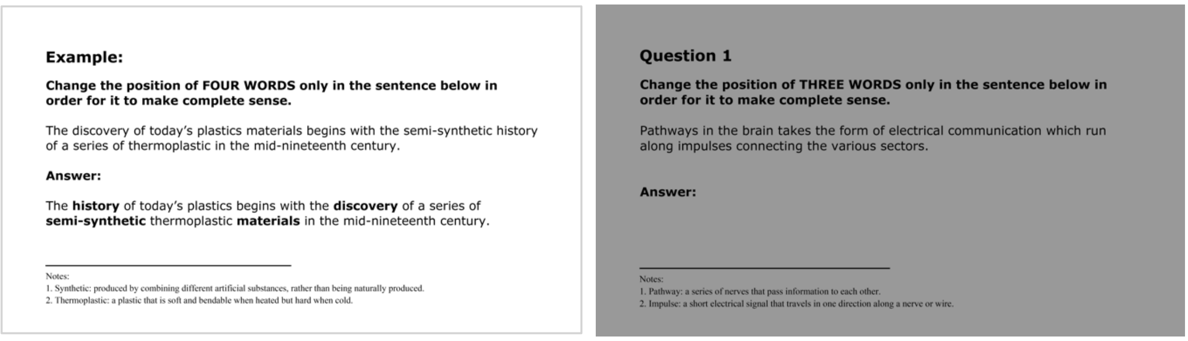


*Figure 1: Examples of the comprehension test, the word-changing questions used in the main experiment.*

The study employed a randomised sequence generator to ensure that each participant encountered materials in varied order, maintaining balance across conditions. This method ensured that all questions appeared an equal number of times against each background colour, with manual adjustments made as necessary to preserve this balance. All the participants participated in the experiment in an offline lab environment equipped with a D65 standardised light source and a standard sRGB display setting. Upon entering the lab, the participants had 1-2 minutes to acclimatise to the surrounding ambient light.

Before commencing the experiment, all participants completed the online Ishihara Colour Blindness Test. Sixteen experimental questions were then presented to the participants randomly.

## Results

In this section, the subjective ratings from the questionnaire are considered. The mean preference scores for each of the eight colour conditions are presented in Figure 2, separately for the non-native English group (left) and the native English group (right). An effect of the colour of the material background on the preference scores was found in both groups (within-subjects ANOVAs, $p < 0.05$). The follow-up test for the mean differences of preference within the non-native English group revealed that 'yellow' was significantly more preferred than 'green' ($p = 0.038$) and 'blue' was significantly more preferred than 'green' ($p = 0.040$). For the native English group, the follow-up test indicates that 'blue' was significantly more preferred than ‘red’ ($p < 0.001$), ‘orange’ ($p = 0.023$), and ‘green’ ($p = 0.003$). Also, ‘purple’ was found to be significantly more preferred than ‘red’ ($p = 0.003$) and ‘green’ ($p = 0.019$).

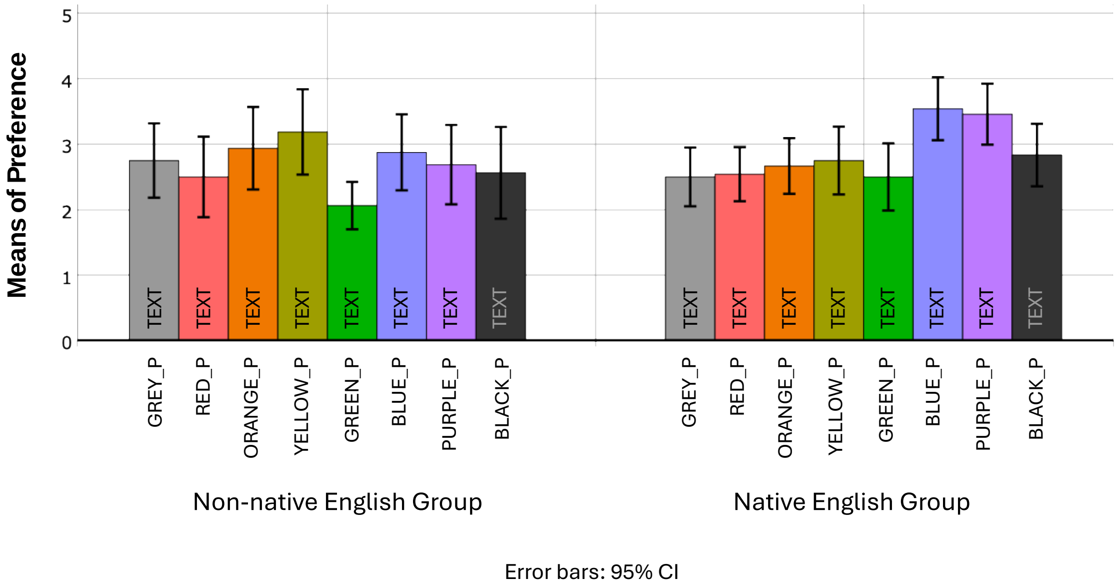


*Figure 2: Subjective assessment of the coloured backgrounds.*

When comparing colour preferences between the two groups, a statistically significant difference was found in the preference across the eight colour conditions (between-subjects ANOVAs, $p < 0.05$). Pairwise comparison tests indicated that preference scores for purple were significantly higher in the native English group than in the non-native English group ($p = 0.039$). However, no statistical significance was found in the pairwise comparison tests for the preference scores for the other seven colours between the two groups ($p > 0.05$).

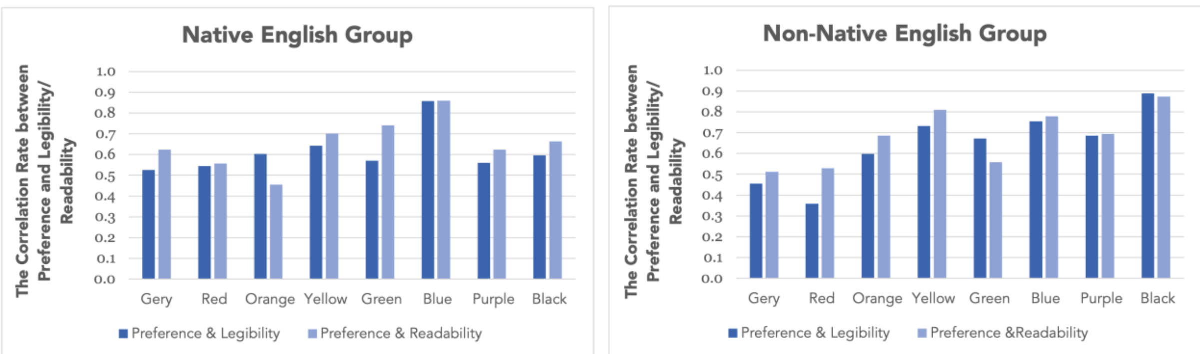


*Figure 3: The correlation rate between Preference and Legibility/ Readability.*

Generally, the subjective ratings for legibility and readability were quite similar to each other and this might indicate that participants struggled to understand the distinction between them even though definitions were provided in the experiment. We also note that participants’ preference scores and their scores for readability and legibility were correlated. Figure 3 shows the correlation between preference and legibility (blue bars) and preference and readability (orange bars) for the native English participants.

In this section, we consider the objective scores from the text-comprehension assessment. Recall that performance in this test is assessed by a per cent correct figure which indicates how completely each participant found the required corrections (movements of words within sentences) to make the sentences make sense. Figures 4-5 show the mean correction rates and response times respectively across all eight colour conditions for both native and non-native English groups. The data reveal that the non-native English group showed lower correction rates in the tests compared to the native English group (Figure 4) which is, of course, not surprising. Additionally, the non-native English group spent more time on the comprehension tests than their native counterparts (Figure 5). It also suggests that both performance rates and time durations of individuals were more varied in the non-native English group than in the native English group, as evidenced by the wider error bars in general. Irrespective of the participants' language background, nonetheless, the colour of the material background had no significant impact on performance rates and response times in these assessments (within-subjects ANOVAs, $p > 0.05$).

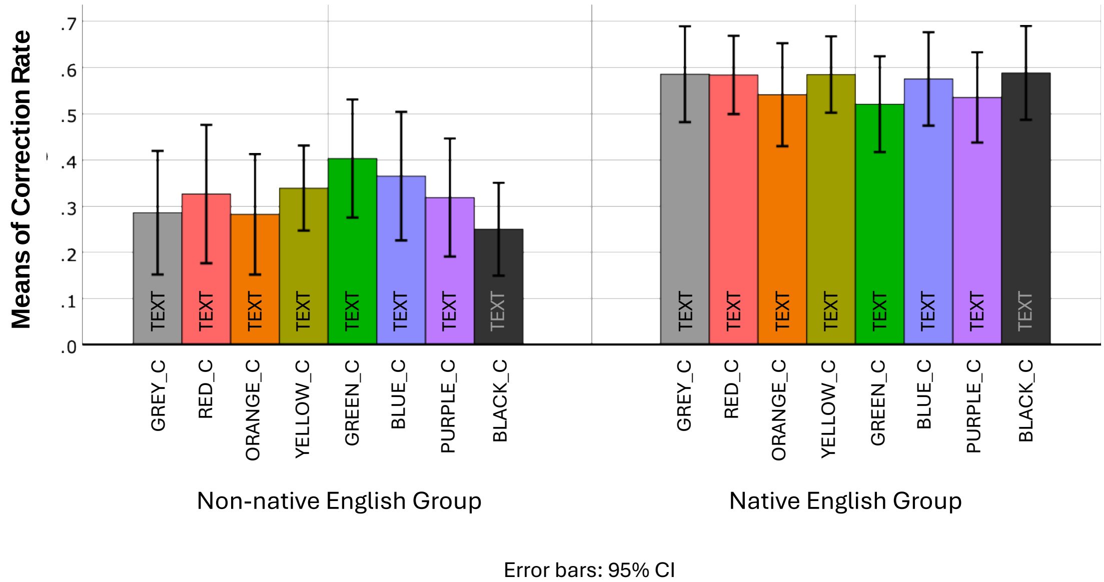


*Figure 4: Performance of native English and Non-native English participants.*

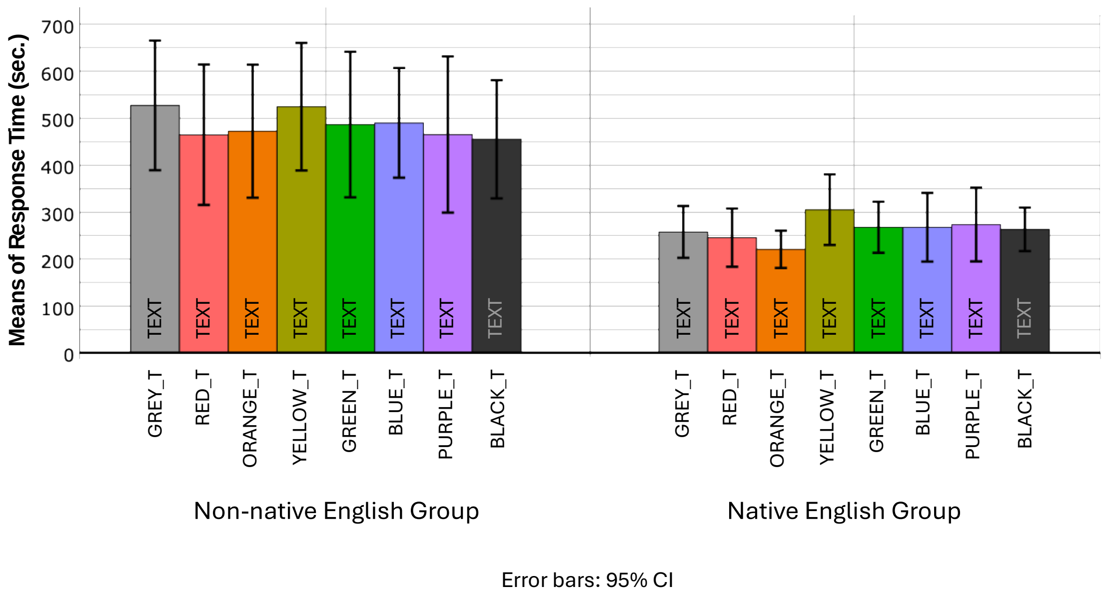


*Figure 5: Response time for native English and Non-native English participants.*

When considering all colour conditions (the averages of differences for the eight colour conditions for each group), the non-native English group had statistically significantly lower correction rates (0.32 ± 0.15) compared to those for the native English group (0.56 ± 0.15), t (78) =-7.053, $p$ < 0.001 (see the left-hand pane in Figure 6). Also, they spent statistically significantly more time (485.83 ± 192.98) compared to the ones for the native English group (262.94 ± 110.90), t (44.72) =5.915, $p$ < 0.001 (see the right-hand pane in Figure 6). These observations were not surprising, as they are consistent with what would be predictable based on differences in language understanding and proficiency between the two groups.

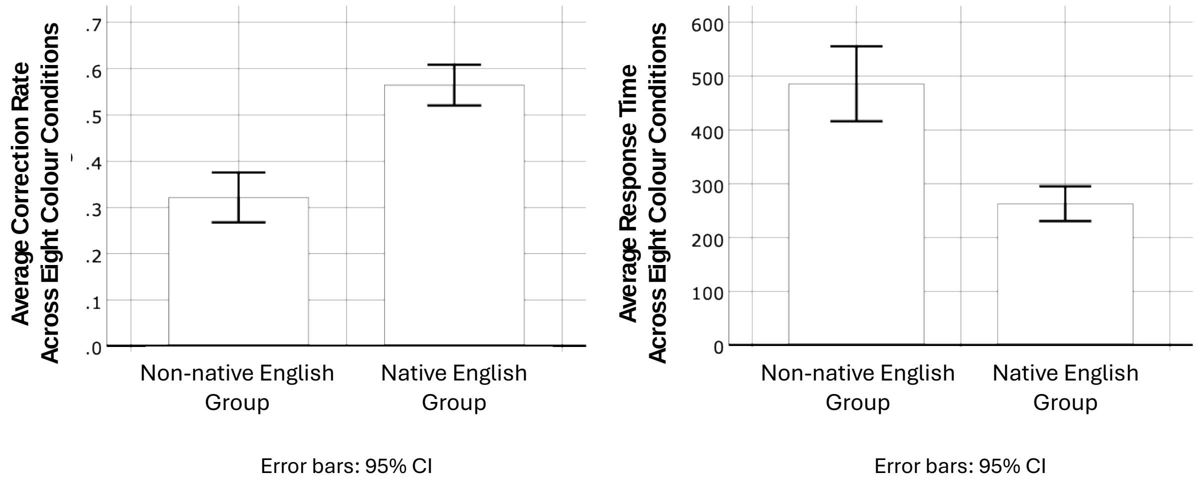


*Figure 6: Summary comparison for the two participant groups.*

Although subjectively participants prefer some coloured backgrounds more than others and rate legibility and readability as being higher in some coloured backgrounds when we look at objective performance there is no statistically significant effect of background colour overall. However, what if there is no mean effect of colour when averaged over all participants but that different colours are effective for different participants? Table 3 shows a visualisation of the colours with the best performance score and the worst performance score.

| Participant | Performance | | | Participant | Performance | | |
|---|---|---|---|---|---|---|---|
| | Best | Worst | Difference | | Best | Worst | Difference |
| P1 | 100.00% | 33.57% | 66.43% | P13 | 100.00% | 33.57% | 66.43% |
| P2 | 75.00% | 20.00% | 55.00% | P14 | 72.73% | 38.57% | 34.16% |
| P3 | 100.00% | 36.92% | 63.08% | P15 | 76.92% | 21.11% | 55.81% |
| P4 | 100.00% | 38.18% | 61.82% | P16 | 100.00% | 33.57% | 66.43% |
| P5 | 100.00% | 21.59% | 78.41% | P17 | 76.92% | 15.00% | 61.92% |
| P6 | 100.00% | 26.92% | 73.08% | P18 | 100.00% | 21.54% | 78.46% |
| P7 | 100.00% | 30.83% | 69.17% | P19 | 75.00% | 31.67% | 43.33% |
| P8 | 57.69% | 15.56% | 42.14% | P20 | 66.67% | 36.67% | 30.00% |
| P9 | 100.00% | 36.81% | 63.19% | P21 | 70.00% | 23.74% | 46.26% |
| P10 | 100.00% | 49.65% | 50.35% | P22 | 70.00% | 34.09% | 35.91% |
| P11 | 100.00% | 33.57% | 66.43% | P23 | 100.00% | 21.11% | 78.89% |
| P12 | 100.00% | 31.41% | 68.59% | P24 | 65.00% | 24.29% | 40.71% |

*Table 3: The visualisation of the best and worst performance colour.*

The differences between best and worst colours for individual participants are quite marked; there is a wide range of performance differences between the best and worst performing colours, from 30% to 78.89%, with a mean of 58.17%. Note that 14 out of 24 participants (58%) scored 100% on their best-performing colour. There is a possibility that these data reveal that colour may have an effect, albeit one that is not common to all participants but is personal. Figure 7. Shows the number of times that each coloured background was the best or worst performing background; note that on average blue is both the best and worst performing colour.

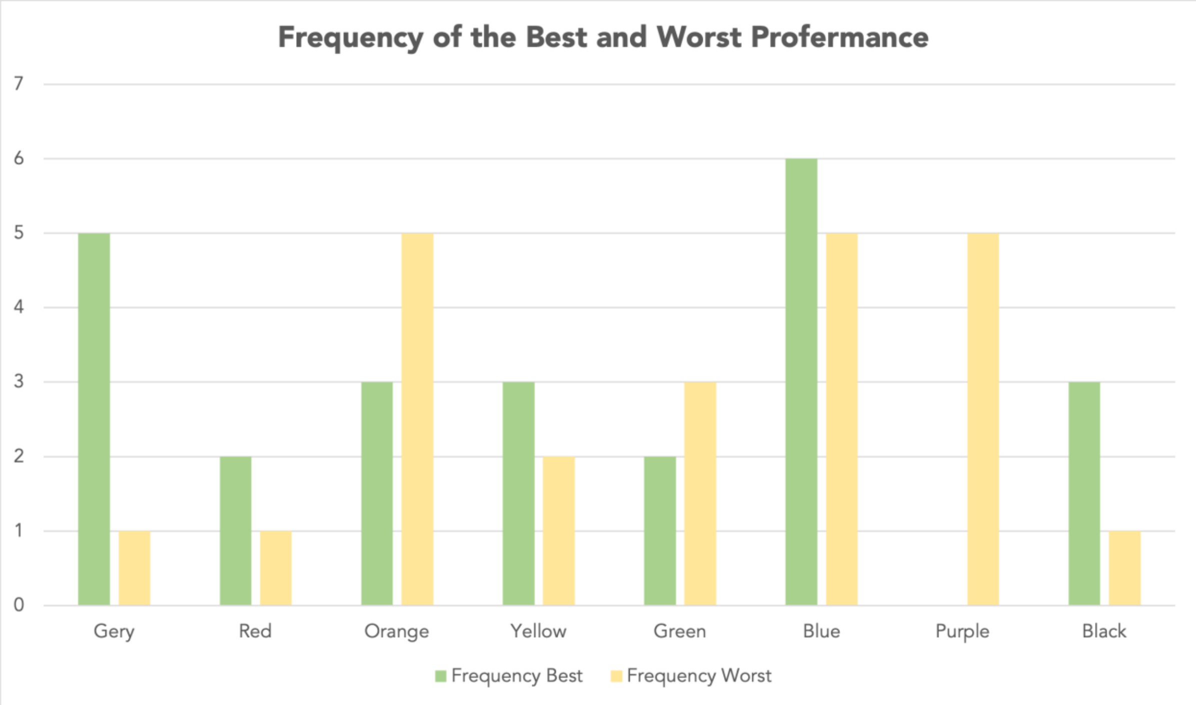


*Figure 7: The frequency of the best and worst performance colour.*

## Discussion

The study found no significant impact of background colour on correction rates and response times within each group, suggesting that background colour alone may not influence comprehension as previously thought (within-subjects ANOVAs $p > 0.05$). However, the differences in correction rates and response times between the native and non-native English speakers were substantial as we might expect based on linguistic proficiency (t (78) = -7.053, $p < 0.001$; t (44.72) = 5.915, $p < 0.001$). These findings underscore the complexities of cognitive processing in second-language comprehension, highlighting the greater challenges non-native speakers face in such settings.

Interestingly, the subjective analysis revealed a significant effect of background colour on the preference scores in both groups (within-subjects ANOVAs $p < 0.05$), with notable preferences for certain colours like blue and purple over others like red and green. This effect, which varied significantly between the native and non-native groups (between-subjects ANOVAs $p < 0.05$), suggests that aesthetic and perceptual factors influenced by cultural and individual differences may play a more prominent role in the subjective experience of digital learning environments than in the objective performance measures like comprehension. Participants tended to rate their preferred coloured backgrounds highly in terms of readability and legibility but these scores were not in agreement with objective performance. These observations suggest that while background colour may not directly influence learning effectiveness in terms of comprehension, it may affect learner engagement and satisfaction. Such findings could be very important for educational content designers who aim to create more inclusive and effective digital learning materials.

Although no effect of colour on objective comprehension performance was found, other studies have found a statistically significant effect in related or similar tasks. In one study, for example, cognitive performance was assessed on-screen for different coloured backgrounds; error rates for red and purple backgrounds were significantly lower than for yellow [40] (Duan *et al.*, 2018). In another study, where cognitive performance was assessed for different coloured screens, it was found that performance was worse for red than for the other seven colours relative to a grey baseline [41] (Booker and Franklin, 2016). In a study using VR and background colour, it was found that blue and green induced lower error rates than red, orange, yellow and purple [42] (Xia *et al.*, 2021). It is not clear what can be concluded by looking at these studies as a group. We note that the participant group size in these studies was 24 native English participants (this study), 27 Chinese participants (14 females and 13 males) [40] (Duan *et al.*, 2018), three hundred and fifty-nine children from 11 schools [41[ (Brooker and Franklin, 2016) and 70 participants (35 males and 35 females) [42] (Xia *et al.*, 2021). Perhaps large participant sample sizes are necessary for robust results.

We considered the possibility in this study that although there is no statistically significant effect of colour background on comprehension performance, some colours may be more effective for individual participants. Studies with coloured overlays on paper have been conducted for many decades with some evidence that colour can affect performance [43] (Wilkins *et al.*, 2001); however, in these studies, it is often reported that different colours are effective for different participants. However, although our data are suggestive that this may be the case, much more work would be needed to verify this. It would be interesting, for example, to repeat the same study with the same participants after a certain time interval to see if the colours that people performed well with remain stable.

The difference in preferences for the different groups of learners may advocate for a nuanced approach to designing educational content that considers both cognitive load and aesthetic appeal to accommodate a diverse learner population. Future research should explore other elements of digital material design, such as typography and layout, and their interaction with colour to further refine our understanding of optimal digital learning environments. Additionally, given the significant differences observed between native and non-native speakers, educational materials should be tailored to address these differences, potentially by incorporating adaptive features that adjust content based on a learner's language proficiency. Expanding the scope of future studies to include other demographic factors such as age, educational background, and cultural context will also be crucial in developing more comprehensive guidelines for educational media design.

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