Pilot Study on Spatial Reading Design to Support Character Recognition in Individuals with Dyslexia*

Takashi Yamazoe[1*,2], Komaro Endo[1] , Kazuya Iijima[1] , Nayoung Lim[2], Yushi Ouchida[2] and Hanae Ikeshita[3†]

[1] Shonan Institute of Technologies, 1-1-25 Tsujido Nishi-Kaigan, Fujisawa, Kanagawa, Japan
[2] Musashino Art University, 1-736, Ogawa-cho, Kodaira, Tokyo, Japan
[3] Sagami Women's University, 2-1-1 Bunkyo, Minami, Sagamihara, Kanagawa, Japan

Abstract

Dyslexia is characterized by difficulty in reading sentences due to differences in character recognition compared to typical development. Recently, information technology has transformed communication styles, enabling access from virtually anywhere. However, most information technologies still rely heavily on textual content. As a result, individuals with dyslexia often encounter difficulties and require digital literacy support through improved character design. Previous research has indicated that dyslexia involves unique spatial recognition abilities. In the present study, the authors aimed to explore the potential of this distinctive spatial recognition using three-dimensional font design within a mixed reality environment, as a means of supporting digital literacy. Three-dimensional font objects were created using solid depth extrusion and stroke-order-following depth extrusion, applied to two Gothic fonts. These objects were rendered with two types of micro-facet material appearances. Four different types characters were selected. Resulting in a total of 32 three-dimensional font stimuli. Participants evaluated the stimuli using a subjective evaluation method. They rated their impressions of each font object by responding to twelve questions on a Likert scale. The results indicated that three-dimensional font objects improved character shape recognition in both individuals with dyslexia and typically developing individuals. However, the detailed expressions of depth extrusion and micro-facet material properties elicited different impressions between the two groups. These findings suggest that three-dimensional character expressions may be beneficial for supporting digital literacy in individuals with dyslexia. Furthermore, the details of depth extrusion and micro-facet rendering appear to be key factors in character recognition for font design targeted at dyslexia.

Keywords

Dyslexia, Font design, Mixed Reality, Spatial recognition, Micro-facet, Subjective evaluation

1. Introduction

Dyslexia is a reading and writing disorder caused by difficulties in recognizing character shapes. Individuals with dyslexia typically demonstrate normal levels of intelligence, comprehension, and verbal communication; however, they consistently struggle with reading and writing tasks. Due to this distinctive characteristic of literacy processing, the challenges faced by individuals with dyslexia extend beyond the acquisition of basic literacy skills, affecting nearly all aspects of learning and knowledge acquisition. This condition can significantly hinder their educational development and overall personal growth [1]. Dyslexic students in higher education show anxiety levels that are well above what is shown by students without learning difficulties. This anxiety is not limited to academic tasks but extends to many social situations [2]. Furthermore, differences in receptive language abilities among individuals with dyslexia have been shown to impact executive functions [3]. These findings suggest that such differences influence not only academic learning but also broader aspects

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1* Corresponding author.
† These authors contributed equally.

yamazoe@info.shonan-it.ac.jp (T. Yamazoe); ikeshita_hanae@isc.sagami-wu.ac.jp (H. Ikeshita)
0000-0003-4934-2143 (T. Yamazoe); 0000-0001-6658-0341 (H. Ikeshita)

of everyday social and psychological functioning. Mind wandering, as a common issue in daily functioning, is frequently observed in individuals with dyslexia. The study of mind wandering in individuals with dyslexia suggests that it may be attributed to a lack of fluency, weaknesses in working memory, or a higher perceived difficulty of the text [4]. These findings confirm that children with dyslexia or DLD (Developmental Language Disorder) are at-risk for reading comprehension difficulties but for different reasons, because of weak decoding in the case of dyslexia or weak oral language skills in the case of DLD [5]. This indicates the importance of implementing literacy support to facilitate reading. In fact, it is known that text-to-speech support can help reduce mind wandering [4]. Thus, literacy support for individuals with dyslexia is not merely an educational aid, but an essential intervention that impacts both their educational development and overall personal growth. To construct literacy support for dyslexia, phonological cues is not work for reading and learning. Because, phonological cues of word recognized is not difference between Dyslexia and typical development. In case of Dutch children— with or without dyslexia—do not seem to show sensitivity to phonological cues for word class in word learning [6]. On the other hand, survey of multisensory teaching and learning suggest that it is equally important and unusual to state that there were no discussions or comments from teachers at any point in the data collection about a multisensory approach having no impact at all on learning, yet there were many opportunities across the research study for participants to state this [7].

The present study aimed to incorporate multimodal sensory elements—including spatial recognition, material appearance, and mixed reality. The font design was constructed using depth expression, material properties, and a Gothic typeface to support literacy in individuals with dyslexia.

2. Spatial recognition on Dyslexia

The visibility and underlying mechanisms of dyslexia have been explored in previous study to guide the development of effective literacy support strategies. In tasks involving impossible figures in 2D graphics, individuals with dyslexia have been observed to respond more quickly than those with typical development [8]. However, the accuracy of distinction in individuals with dyslexia is similar to that of typically developing individuals [9]. These findings suggest that individuals with dyslexia are highly capable of distinguishing graphical information, and their ability to understand it is comparable to that of typically developing individuals. The ability to make high-accuracy distinctions without full understanding is a characteristic feature of advanced spatial recognition skills. Other study reported use of Virtual Reality (VR) environment with individuals with dyslexia. Adolescents with dyslexia demonstrated better visuospatial performance on a pseudo real-life test than their nondyslexic peers [10]. Rehabilitation using a virtual reality system can enhance treatment adherence and reduce symptoms by providing engaging activities for children with dyslexia [11]. These findings indicate that virtual environments may not pose difficulties for individuals with dyslexia and are likely to contribute positively to the enhancement of literacy-related cognitive functions. The study of spatial frequency revealed differences in contrast sensitivity between individuals with dyslexia and those with typical development and chromatic contrast sensitivity thresholds did not correlate with any of the reading measures [12]. This finding aligns with differences in spatial frequency responses, reflecting the distinct spatial recognition patterns observed in individuals with dyslexia compared to those with typical development. In literacy support approaches that leverage depth perception through parallax, the integration of depth and color perception has been shown to enhance the discrimination of characters and individual strokes [13]. The study of material appearance indicates that the ability to distinguish macro-facets, such as on the smooth–rough scale, differs between individuals with dyslexia and those with typical development. On the other hand, the ability to distinguish micro-facets, such as on the gloss–matte scale, appears to be similar between the two groups [14]. This finding suggests that micro-facet is able to use cue of distinguish character shape. Research of font type face readability reported that font types have an impact on readability for both people with and without dyslexia [15]. This research results suggest font geometry and pattern are influence to readability to both of with and without dyslexia. However, other research of font type face readability reported that this alternating treatment experiment shows no improvement in reading rate or accuracy for individual students with dyslexia, as well as the group as a whole [16]. It should need to clarify Font type face influence to readability.

In response, the present study incorporated spatial recognition and material perception into font design to create three-dimensional font objects for literacy support. A preliminary evaluation was conducted to assess their readability.

3. Methods

Our spatial recognition operates based on visible space, as it relies on visual sensory input. To reproduce character objects in space with on-demand word display, it is reasonable to utilize Extended Reality (XR), including Augmented Reality (AR), Mixed Reality (MR), and Virtual Reality (VR). The present study focuses on three-dimensional font design, leveraging spatial recognition as a means of literacy support. MR provides an appropriate environment for displaying virtual objects exclusively as three-dimensional fonts during experimental sessions. Readability and user impressions were evaluated by participants using a twelve-items of Likert scale.

3.1. Three-dimensional font design

Spatial recognition arises from the judgment of three-dimensional locations and the ability to distinguish between individual objects. Therefore, stimuli composed of three-dimensional characters were created using standard graphical font designs with depth extrusion. The stimuli were constructed using 3D content creation software (Blender, Blender Foundation) and displayed through a head-mounted display (HMD; Vision Pro, Apple) via a game engine (Unity, Unity Technologies). Depth extrusion was implemented under two conditions, based on previous research suggesting that character recognition improves when stroke order and depth correspond. In the solid depth extrusion condition, depth was extruded uniformly and did not follow the stroke order (Figure 1 shows front view, Figure 2 shows perspective view). In the stroke-order-following depth extrusion condition, the extrusion corresponded to both the front-to-back depth and the stroke order from start to end (Figure 3 shows front view, Figure 4 shows side view). To assess the effect of surface properties, two different micro-facet materials—gloss and matte—were used for the textures (Figure 1 shows matte finish, Figure 3 shows glossy appearance), as the perceived appearance of three-dimensional objects is influenced by material properties and lighting. Prior studies have confirmed that micro-facet perception is largely similar between individuals with dyslexia and those with typical development [14]. The micro-facet texture influences perceived hue, causing glossy and matte surfaces to appear as different colors even when rendered with the same hue setting. Therefore, the RGB values for the matte textures were based on a darker color setting, and their color parameters were empirically measured. The RGB values for the glossy textures were subsequently derived from the corresponding matte color values. Two Gothic-style fonts were used for the character shapes: UD Shin-Gothic (OpenType, Morisawa, Figure 1) and Source Han Sans (OpenType, Adobe, Figure 5). Characters were selected from various writing systems. Four types were chosen to generate the three-dimensional character objects: a number (Figure 1, 2), an alphabet letter (Figure 5, 6), a Chinese character (kanji, Figure 3, 4), and a hiragana character (Figure 7, 8). In total, Thirty-two objects of stimuli were prepared for the evaluation.

Figure 1: Front view of a three-dimensional font object of the number eight, featuring solid depth extrusion and a matte finish, in UD Shin-Gothic font.

Figure 2: Perspective view of a three-dimensional font object of the number eight, featuring solid depth extrusion and a matte finish, in UD Shin-Gothic font.

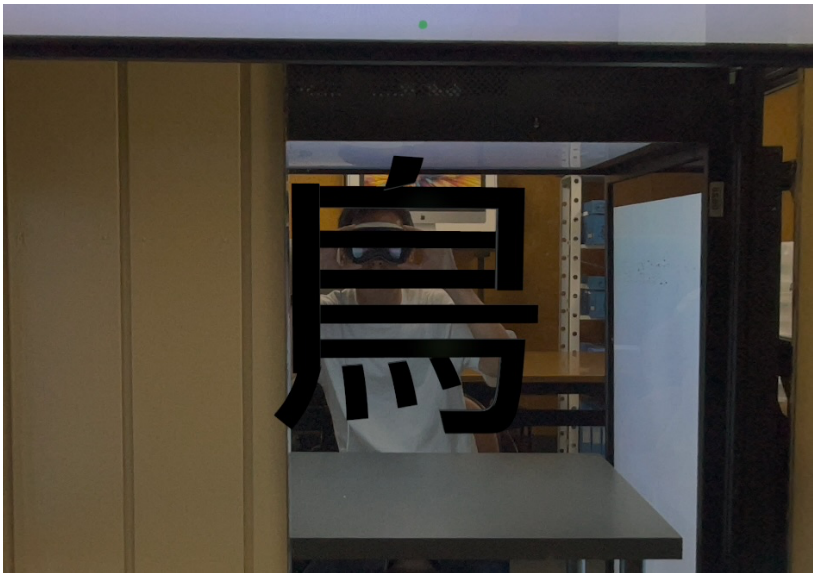

Figure 3: Front view of three-dimensional font object of the Chinese character “Bird,” featuring stroke-order-following depth extrusion and a glossy appearance in UD Shin-Gothic font.

Figure 4: Perspective view of three-dimensional font object of the Chinese character “Bird,” featuring stroke-order-following depth extrusion and a glossy appearance in UD Shin-Gothic font.

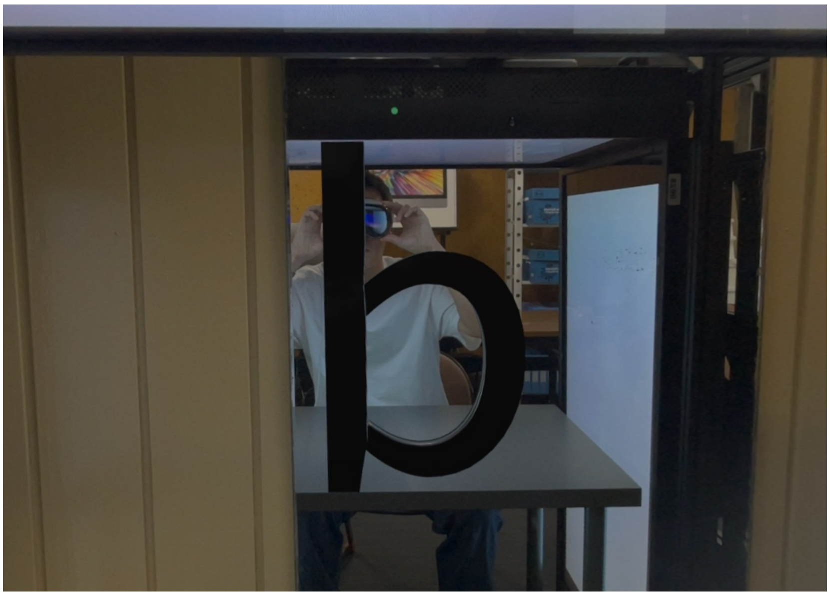

Figure 5: Front view of three-dimensional font object of the Alphabet character “b,” featuring stroke-order-following depth extrusion and a glossy appearance in Source Han Sans font.

Figure 6: Perspective view of three-dimensional font object of the Alphabet character “b,” featuring stroke-order-following depth extrusion and a glossy appearance in Source Han Sans font.

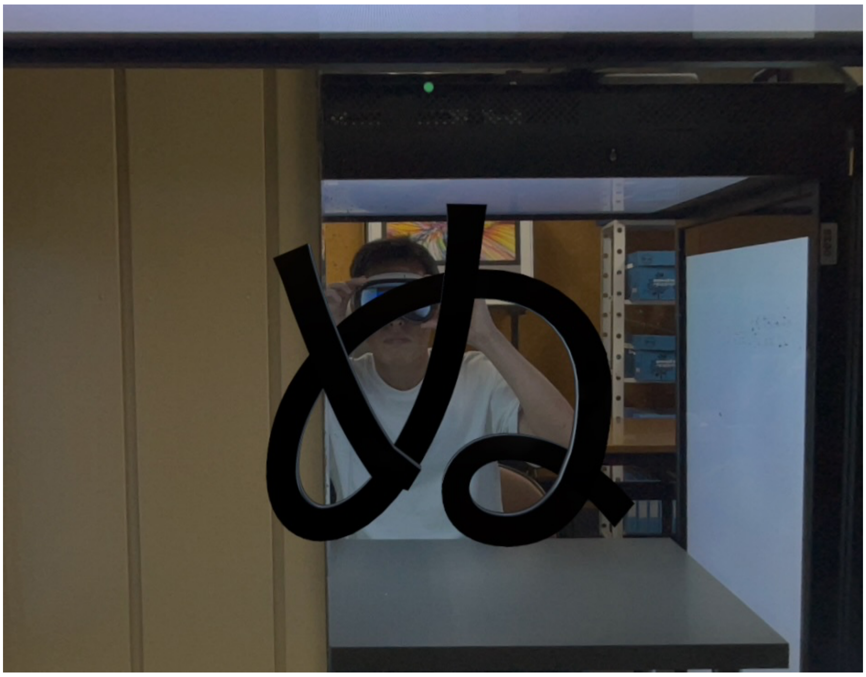

Figure 7: Front view of three-dimensional font object of the Hiragana character "Nu," featuring stroke-order-following depth extrusion and a glossy appearance in UD Shin-Gothic font.

Figure 8: Front view of three-dimensional font object of the Hiragana character "Nu," featuring stroke-order-following depth extrusion and a glossy appearance in UD Shin-Gothic font.

3.2. Participant

One female participant with dyslexia took part in the study. She was 13 years old and had been formally diagnosed with dyslexia by a medical institution prior to participation (Figure 9). A female participant with typical development also participated as a control. She was 24 years old (Figure 10). Informed consent regarding the content and purpose of the study was provided to the participants and their guardians in advance, and consent was obtained voluntarily.

Figure 9: Participant with dyslexia looks three-dimensional font objects in front of illuminated booth.

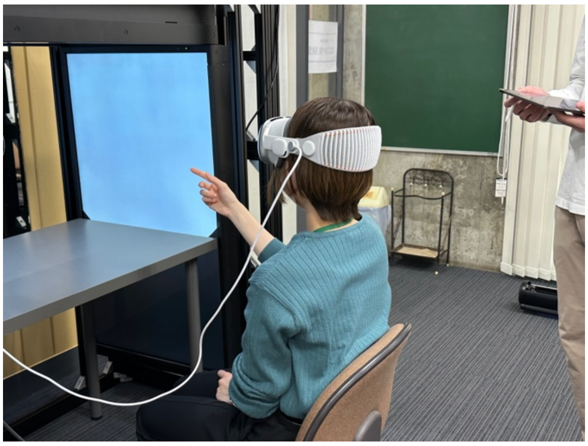

Figure 10: participant with typical development looks three-dimensional font objects in front of illuminated booth.

3.3. Apparatus and stimuli

Thirty-two three-dimensional font objects are presented using a head-mounted display (HMD; Apple Vision Pro, Apple), as shown in Figure 11. The HMD presents a MR environment through a video see-through composite system. Size of three-dimensional font objects set height 20cm, width 20cm, depth 3cm. Location of three-dimensional font objects set 110cm from ground, 50cm from face. This location setting can display in illuminated booth (Figure 9, 10). Illumination condition was set to 319lx of illuminance, 0.5 of diffuseness of cubic illuminance measurement (Cuttle, C., 2014).

Figure 11: Head-mounted display for display three-dimensional font object in mixed reality environment.

3.4. Subjective Evaluation

Participants observed and memorized 12 items assessed using a 7-point Likert scale evaluation (Figure 12) before wearing an HMD. Participants scored their impression of stimulus. The evaluation consisted of 12 items assessed using a 7-point Likert scale ranging from 3 to 0 to 3 (Both side positive). The evaluated items included glossiness, smoothness, clarity of stroke order, legibility of characters, naturalness, perception of depth, structural clarity, transparency, legibility from different viewing angles, realism, sharpness, and overall character readability. The experimenter read twelve items and after participants answered 7-point Likert scale. experimenter completed the evaluation form using a tablet PC (iPad Air, Apple Inc.). Direct reports of interview style were obtained from the participants after completion of all trials.

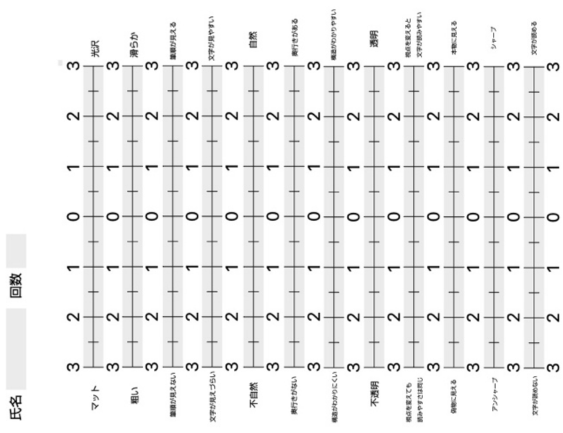

Figure 12: Twelve items of a 7-point Likert scale evaluation sheet in Japanese language.

3.5. Procedure

After obtaining informed consent, participants received an explanation regarding the operation of the head-mounted display (HMD). Once participants demonstrated an understanding of the operation procedure, they wore the HMD and adjusted the lens position to match their interpupillary distance, ensuring comfortable viewing of the stimuli. Following the adjustment, the stimulus presentation began. Each stimulus was presented for 60 seconds, following a 30-second interval. During the presentation period, participants provided verbal evaluations of 12 items using a 7-point Likert scale. This procedure was repeated 32 times. The presentation order of the 32 stimuli was randomized across participants. After completing the evaluations of all 32 stimuli, participants removed the HMD and took part in direct interviews to provide qualitative reports.

3.6. Analysis

Both participants observed the stimuli twice, and depth expression was considered a potential influencing factor. Therefore, a two-way analysis of variance (ANOVA) was conducted to compare evaluations. First, all responses on the 12 evaluation items using the 7-point Likert scale were converted from a 3-0-3 format to a -3-0-3 format. The converted responses were then subjected to a two-way analysis of variance (ANOVA) with participant and depth expression as factors. For post hoc comparisons, Bonferroni correction was applied to examine differences between levels of participant and depth expression, as well as their interaction effects.

3.7. Results

The results of glossiness impression (micro-facet) present in Figure 13. The dyslexic participant demonstrated a perception of glossiness in three-dimensional font objects that was less dependent on surface texture compared to typically developing individual ($p < .01$, $F = 8.244$).

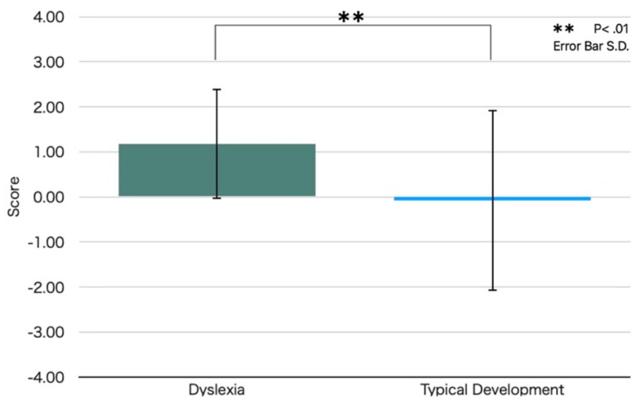

Figure 13: The results of glossiness impression (error bar S.D.).

Figures 14 and 15 present the results of naturalness ratings. While the typically developing participant perceived the three-dimensional font objects as unnatural, the participant with dyslexia provided more neutral evaluations (P < .01, F = 7.421). Additionally, the stroke-order-following depth extrusion was perceived as more unnatural than the solid depth extrusion (P < .001, F = 56.123). No interaction was observed between participant and depth expression.

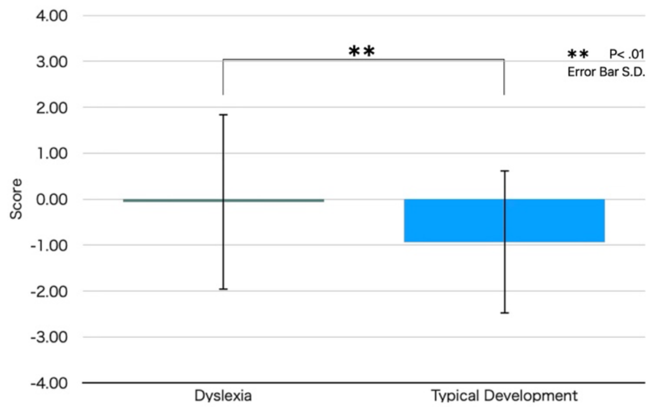

Figure 14: The results of naturalness compare among participants (error bar S.D.).

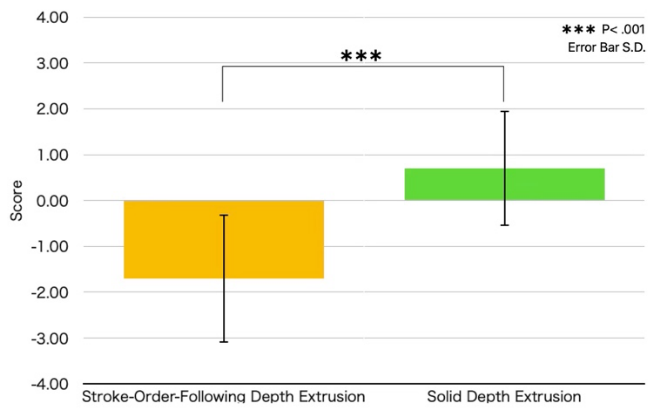

Figure 15: The results of naturalness compare among depth expressions (error bar S.D.).

Figures 16 present the results of clarity of stroke order ratings. Compared to the typically developing participant, the participant with dyslexia found the stroke order of characters easier to perceive when presented as three-dimensional font objects (P < .001, F = 15.185). Furthermore, the stroke-order-following depth extrusion was perceived as clearer in terms of stroke order than the solid depth extrusion (P < .001, F = 23.044). An analysis of interaction effects revealed that, while the typically developing participant found it more difficult to recognize stroke order in the solid depth extrusion condition, the dyslexic participant perceived the stroke order as equally discernible regardless of the type of depth expression (P < .001, F = 17.941).

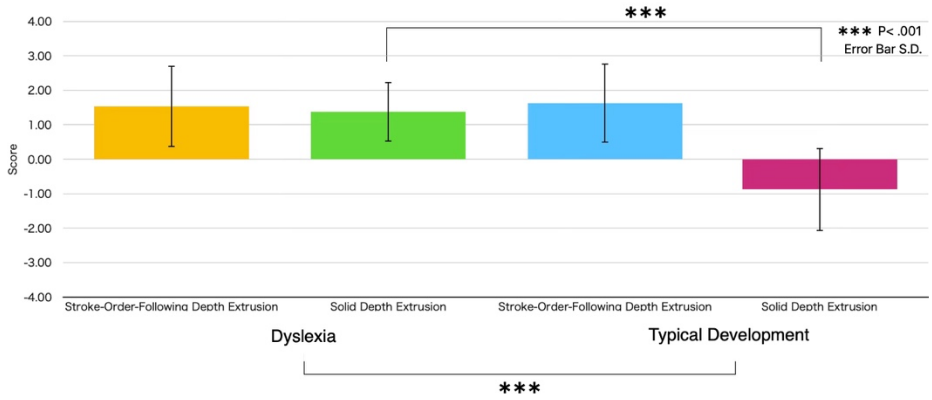

Figure 16: The results of clarity of stroke order impression (error bar S.D.).

Figures 17 present the results of perception of depth ratings. Regarding the perception of depth, the typically developing participant reported a clear sense of depth, whereas the participant with dyslexia provided neutral evaluations (P < .01, F = 9.477). The stroke-order-following depth extrusion was perceived as more effective in conveying depth than the solid depth extrusion (P < .001, F = 135). Analysis of interaction effects (P < .05, F = 5.217) revealed that the dyslexic participant did not perceive depth in the solid depth extrusion condition, in contrast to the typically developing participant, who gave a neutral evaluation of the same condition.

The results of structural clarity present in Figure 18. The participant with dyslexia perceived the structure of the 3D font objects as easier to understand compared to the typically developing participant (P < .001, F = 18.132). The stroke-order-following depth extrusion was found to convey structural clarity more effectively than the solid depth extrusion (P < .05, F = 6.528). Analysis of interaction effects indicated (P < .001, F = 29.817). that the dyslexic participant found the structure easy to comprehend regardless of the type of depth expression, whereas the typically developing participant found the stroke-order-following depth extrusion to be more structurally informative.

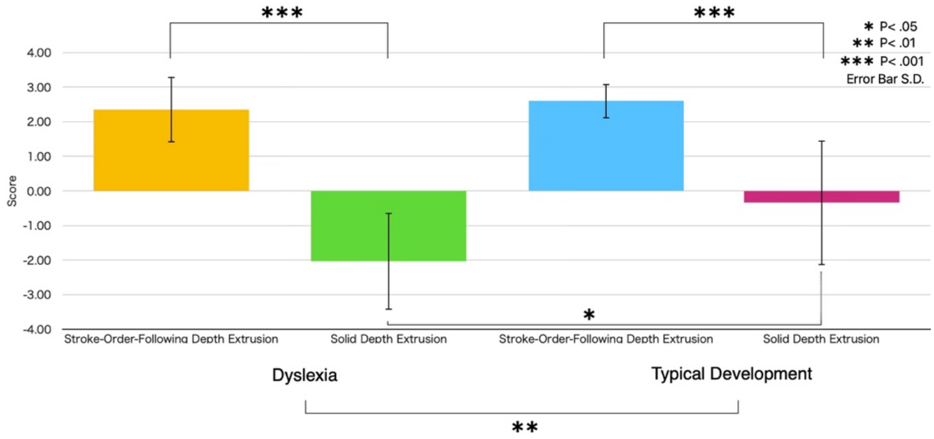

Figure 17: The results of perception of depth (error bar S.D.).

The results of legibility from different viewing angles present in Figure 19. No differences were observed between participants in the evaluation scores for legibility from different viewing angles. Regarding depth expression, the stroke-order-following depth extrusion was perceived as less legible than the solid depth extrusion ($P < .001$, $F = 39.979$). Analysis of interaction effects revealed that, while the dyslexic participant found the solid depth extrusion easier to read when the viewing angle was changed, the typically developing participant gave a neutral evaluation ($P < .001$, $F = 14.392$).

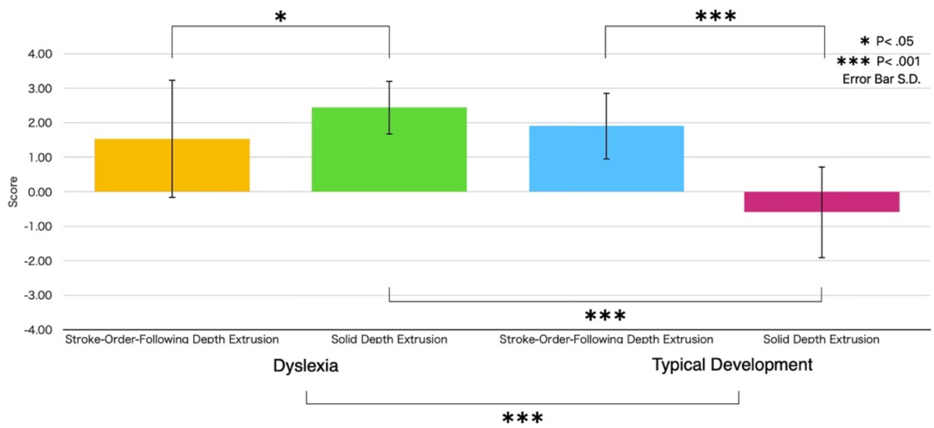

Figure 18: The results of structural clarity (error bar S.D.).

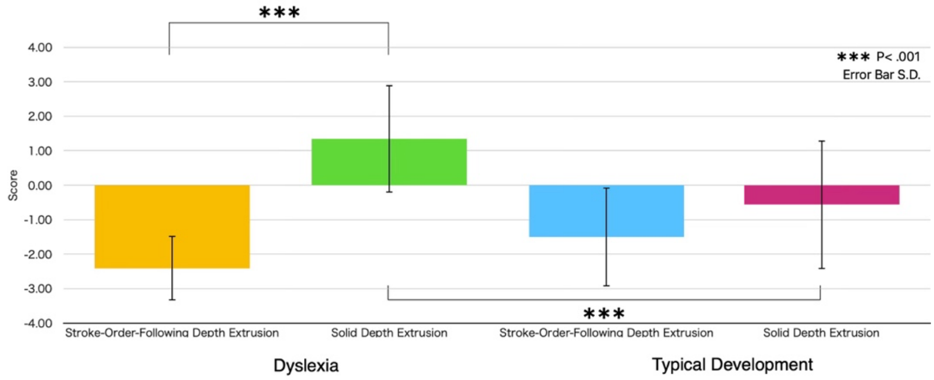

Figure 19: The results of legibility from different viewing angles (error bar S.D.).

The results of realism impression in Figure 20. Regarding the realism impression, the participant with dyslexia reported a stronger sense of artificiality, whereas the typically developing participant provided a neutral evaluation (P < .001, F = 9.312). The stroke-order-following depth extrusion was perceived as less realistic than the solid depth extrusion (P < .001, F = 76.969). Analysis of interaction effects (P < .01, F = 7.648) indicated that the dyslexic participant perceived greater realism in the solid depth extrusion condition, while the typically developing participant maintained a neutral impression.

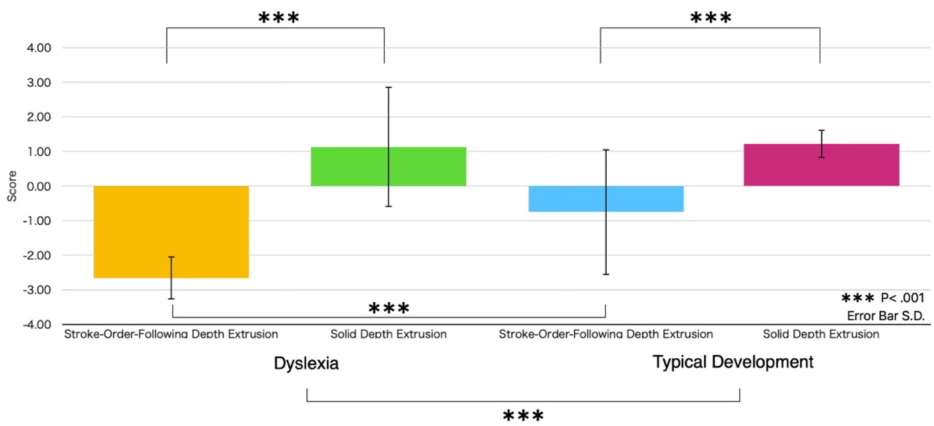

Figure 20: The results of realism impression (error bar S.D.).

Three-dimensional font objects were reported to be easier to read and more effective for distinguishing characters than printed or flat-display characters. The stroke-order-following depth extrusion was considered more effective for learning unfamiliar characters; however, it was perceived as less readable compared to the solid depth extrusion. The participant with typical development indicated that the stroke-order-following depth extrusion was more beneficial for character learning and left a strong impression in terms of memorizing stroke order. In contrast, the solid depth extrusion was not perceived as clearly different from printed or flat-display characters.

4. Discussion

This study evaluated the readability of three-dimensional font object designs for individuals with dyslexia. The results suggest that three-dimensional font objects may be adaptable for literacy support. Findings related to the clarity of stroke order impressions, structural clarity, and depth perception indicate that spatial recognition in individuals with dyslexia plays a role in distinguishing character shapes. This implies that the spatial layout of three-dimensional objects serves as a cue for character recognition. Evaluations of naturalness, legibility from different viewing angles, and realism impressions suggest that different font designs may be required depending on whether the task involves reading continuous text or learning unfamiliar characters. Solid depth extrusion was perceived as more natural and better suited to viewpoint changes, making it more appropriate for reading. In contrast, stroke-order-following depth extrusion exhibited clearer structural form and facilitated understanding of stroke order. Perception of glossiness differed between the participant with dyslexia and the typically developing participant. The individual with dyslexia perceived the three-dimensional font objects as glossier. This may suggest that individuals with dyslexia are constantly searching for visual cues to help distinguish character shapes. Moreover, the proposed method of using three-dimensional font objects for literacy support may provide a learning environment that accommodates both individuals with dyslexia and those with typical development. It should be noted, however, that the findings of this study are based on a limited number of participants. Further research with a larger sample is necessary to clarify the readability of three-dimensional font objects. No significant differences in readability were found among different font shapes. This result suggests that similar typeface as include Gothic typefaces does not influence to readability. This result support no improvement in reading rate or accuracy for individual students with dyslexia, as well as the group as a whole [16]. Although the present study focused exclusively on Gothic typefaces, future research should also examine font designs incorporating Sans-Serif typefaces. Additionally, the present study used only dark-colored (near-black) font objects, and future research should explore variations in hue.

5. Conclusions

In conclusion, the present study conducted a preliminary evaluation of three-dimensional font object designs in a mixed reality (MR) environment, aimed at supporting literacy learning for individuals with dyslexia. Despite the limited number of participants, the findings suggest that three-dimensional font designs have the potential to facilitate both reading and writing acquisition. Furthermore, the results suggest that individuals with dyslexia are likely to possess enhanced spatial recognition abilities. Moving forward, further studies will aim to increase the sample size to enhance the validity of the results, and to explore a wider range of design elements—including typefaces and color variations—in order to develop more readable and accessible font designs for diverse learners.

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Declaration on Generative AI

The authors declare that GPT-5 was employed solely for the purpose of grammar correction and language refinement in the preparation of this manuscript. All content generated through this process was critically reviewed and revised by the authors, who take full and independent responsibility for the scientific and intellectual integrity of the published work.

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