

Article

Eye-Tracking Study on Reading Fluency in Relation to Typeface Pleasantness Influenced by Cross-Modal Correspondence Between Taste and Shape

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Abstract: Reading fluency depends on the typographic design. Letters can have different shapes that evoke different feelings in the reader and influence reading fluency. Previous studies that explored the link between typeface shape and taste and its impact on reading and readers' attitudes mainly focused on shorter texts or individual words. In contrast, our study investigated how the taste (sweetness) attributed to the typeface is related to reading fluency and the pleasantness of the typeface during reading longer texts, and whether these relationships are the same in children and adult readers. We found that readers of both age groups perceived rounded letters as sweeter than angular letters. The perceived sweetness correlated positively with the pleasantness of the typeface and reading fluency. Younger readers showed a higher general rating of sweetness and a stronger relationship between the perceived sweetness and the pleasantness of the typeface than older, more experienced readers. This suggests that the sweeter and more pleasant the typeface is perceived to be, the faster it can be read. When fast processing of longer texts is required, we recommend the use of rounded typefaces with more organic shapes, including serif typefaces with some characteristics of old-style typefaces, rather than using angular, sans serif typefaces.



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Keywords: typeface shape; cross-modal correspondence; taste; sweetness; pleasantness; reading fluency

1. Introduction

Typographic design, especially the shape of typefaces, plays a crucial role in reading as it influences both perception and cognitive processing during reading as well as the reader's mood by affecting their emotional response and sense of pleasantness when interacting with certain letterforms [1–3].

The shape of letters and typography as a whole have a direct impact on text legibility [1–3], clarity of the information presentation [4,5], and reading fluency [6–11]. Typography can also affect the comprehension of content [12], which has been identified as an important aspect of reading fluency [13,14], alongside letter recognition and reading speed [15,16]. Reading fluency is influenced by various typographic factors, including type size [17,18], typeface shape, legibility [11,19,20], overall typographic design [21], and resolution when reading on a screen—higher resolutions enable a more precise rendering of letters and better reading fluency [6,22,23].

Poor reading fluency hinders information processing and weakens comprehension [24–32]. Reading fluency influences the learning process [33] and metacognition [34,35]. Research on

difficult-to-read typefaces, which some claim to introduce a “desirable difficulty”, such as Sans Forgetica, has mostly found no benefits for comprehension, memory, or even negative effects [36–40]. However, some studies suggest that a more challenging reading experience can enhance processing and recall [29,41–44]. Typography can also provide clues about the type and content of a text [22,45–50], allowing readers to estimate the time needed to read it [8,51]. Better reading fluency generally leads to a more positive attitude toward the text and better comprehension. On the other hand, poorer fluency can lead to a negative attitude, as readers expect to spend more time with a text [29,52–56].

Age is an important factor in reading fluency. Children and adults differ in their cognitive and physiological abilities up to about the fourth grade, after which their letter recognition skills align [57]. For younger readers, typefaces with serifs and varying stroke widths promote more fluent reading [7], while sans serif typefaces with minimal stroke variation lead to fewer errors [58]. Children also benefit from varied letter shapes [58,59], especially children with visual impairments [7]. However, the effect of typography on reading fluency may not be the same for younger (less experienced) and older (more experienced) readers. Research suggests that increasing the desired difficulty level of a typeface can improve reading fluency in adults but may have a negative effect on children [60]. Larger type sizes improve the decoding speed and memory retention in children, but not in adults [59].

Typographic design, especially the shape of typefaces, plays a crucial role not only in the cognitive processing of a text and reading fluency but also in the reader’s mood by influencing their emotional response and sense of pleasantness when interacting with certain letterforms [61–63]. Perceptual studies have shown that shapes, tastes, and sounds can evoke certain emotions, including pleasure [46,61–69]. Rounded and symmetrical shapes trigger more positive feelings than angular or asymmetrical ones [70,71]. Due to cross-modal perception, different sensory modalities are often associated with each other, although these associations may vary across cultures [72–77]. For example, round shapes are associated with sweetness, while square, angular shapes are associated with bitterness and sourness [71,78–81]. Since sweetness is often associated with pleasantness [80,82], round shapes tend to evoke pleasant feelings [83–85]. This concept is widely used in marketing and packaging design [79,86,87]; however, its use in typography for longer texts is still relatively unexplored. The available research suggests that the general effects of shape on emotions can also be applied to this area. Rounded, organic shapes with softer transitions are perceived as more pleasant, while geometric strokes and sharp transitions are perceived as less pleasant [74,88]. The enjoyment of reading different typefaces can influence motivation, focus [21,89], comprehension, and recall [89]. However, there is little research on the relationship between the emotional responses to letter shapes and reading fluency.

This study had two main aims: (1) We aimed to investigate how letter shape influences the perceived sweetness and, consequently, the pleasantness of typefaces. Additionally, we sought to examine how this cross-modal correspondence between shape and taste impacts reading fluency, measured by reading speed, and reading comprehension. Based on previous studies, we anticipated a cross-modal correspondence in the perception of typefaces, such that typefaces with round/rounded shapes would be perceived as sweeter compared to those with angular/pointed shapes. We also hypothesised that round/rounded typefaces would be easier to read than angular/pointed ones. (2) In addition, we wanted to investigate whether the relationship between the perceived sweetness and pleasantness of a typeface and reading fluency differs between younger readers with less experience in reading longer texts and adult, more experienced readers. Previous studies have shown that changing the characteristics of typefaces affects children and adults differently [59,60].

Children also respond differently to colours, shapes, tastes, and smells than adults [90,91]. For this reason, we wanted to compare the relationships between reading fluency and emotional responses to different typefaces in these two groups of readers.

2. Materials and Methods

2.1. Participants

Eighty-eight participants took part in this study during the COVID-19 pandemic. We divided them into two age groups, namely university students and elementary school students. The first age group was composed of 36 university students between 19 and 25 years of age with a mean age of 19.9 years ($SD = 1.4$); 22 of them were female and 14 were male. The second age group comprised 49 (28 female and 21 male) 4th to 6th grade elementary school students aged 10 to 12 years, with an average age of 10.9 years ($SD = 0.6$). We chose children of this age because they are already fluent readers and can read longer texts (according to Chall [92], they entered the developmental stage of reading for learning), but they are not yet experienced readers like university students who can be considered expert (adult) readers (who have reached the construction and reconstruction stages of reading skills) [92].

All participants had normal or corrected-to-normal vision and received no payment for their participation in the study. This study was conducted in accordance with the Declaration of Helsinki. Informed consent was obtained from the participants or their parents/guardians prior to participation in this study.

2.2. Stimuli

Before the main study, we conducted two preliminary studies, which are presented in detail in our 2023 publication [2]. In the first study, we selected the texts for the main study. From various excerpts from textbooks and children's encyclopaedias, we selected 10 texts with 459–509 characters that had comparable content complexity and led to a similar reading fluency. The selected texts provided the highest and most homogeneous reading speed. We also analysed the number of fixations for each text as an additional indicator of reading fluency. The fewer the fixations, the more fluently participants read the text. The texts appeared to be content-wise comparable and suitable for fluent reading by a broader population, including both 4th to 6th graders and adults, and did not include distracting elements such as overly long or complex words and unclear content. We hypothesised that the selected texts would induce a similar cognitive load, as they had comparable content difficulty, similar reading speeds, and a comparable number of fixations. In the second study, we selected the typefaces for the main study.

We categorised typefaces into two groups based on the shape of their main strokes, transitions, and stroke ends (serifs). Typefaces can be described based on their shape characteristics: the form of main (especially rounded) strokes, transitions between strokes, and stroke endings, categorising them as either round/rounded or angular/pointed. Round/rounded typefaces included those with letters that have softer or more organic shapes—forms that resemble natural shapes such as waves, curves, and shapes found in the natural environment. On the other hand, angular/pointed typefaces include those with letters of a more technical design, featuring more angular and sharp forms. Typical typefaces that could be classified as round/rounded include typefaces with characteristics of venetian, galalde, and transitional typefaces [93,94]. Typefaces that could be classified as angular/pointed include some typefaces with characteristics of didone, slab serif, and sans serif typefaces [93,94].

The shape of letters significantly impacts the reader's mood, specifically their emotional response or the sense of pleasantness they feel when reading certain letter shapes [21,95–97]. Previous research [74,81,82,88] has shown that letters with softer or more organic stroke shapes and smoother transitions between strokes and their endings are perceived as more pleasant and are, through multimodal perception, associated with a sweet taste. Letters that are more geometric in shape and have sharper transitions between strokes and their endings are perceived as less pleasant and are not as strongly associated with a sweet taste through multimodal perception. Figure 1 shows two examples of round/rounded typefaces, while Figure 2 shows two examples of angular/pointed typefaces. The term “rounded” or “angular” refers to the round shapes of counters, bowls, lobes, and loops, while “rounded” or “pointed” refers to the transitions between strokes, serifs, and stroke endings and the overall shape of the strokes—stems, crossbars, diagonals, etc.—which in some typefaces (i.e., FG April) are curved rather than straight (as in Verdana).

(A) Pobegli dihur znova ščipa moj cufast kožuh.

(B) Pobegli dihur znova ščipa moj cufast kožuh.

Figure 1. Examples of two round/rounded typefaces: (A) Matilda and (B) Comic Sans MS.

(C) Pobegli dihur znova ščipa moj cufast kožuh.

(D) Pobegli dihur znova ščipa moj cufast kožuh.

Figure 2. Examples of two angular/pointed typefaces: (C) Arial Nova and (D) Birch Std.

In the second preliminary study, we selected ten typefaces to be analysed (Figure 3). The five most appealing typefaces were Chaparral Pro, Comic Sans, FG April Trial, Matilda, and Times New Roman, and had the characteristics of round/rounded shapes, while the five least appealing typefaces had the characteristics of angular/pointed shapes, i.e., Arial Nova, Anka, Nogomet, Sans Forgetica, and Verdana.

Each text was set in one of the typefaces. The type size was adjusted to achieve as uniform an x-height as possible for all typefaces, which varied between 0.17 and 0.20 degrees of visual angle. The average x-height was 0.19 degrees of visual angle ($SD = 0.01$). Due to the different shapes of letters, the number of lines in various texts varied between 10 and 11, with the average number of lines being 10.30 ($SD = 0.48$). In all cases, the line spacing was 140% of the type size.

2.3. Apparatus and Instruments

We used eye-tracking technology to objectively measure reading fluency. We used a Tobii X120 (Stockholm, Sweden) eye-tracking system in combination with Tobii Studio 3.4.8 software [98] (which was available at the time of our study) to monitor the participants' eye movements. The device works by detecting the reflection of infrared light on the cornea. Infrared emitters on the front of the device project specific IR light patterns, which are then reflected by the cornea. An inbuilt infrared-sensitive camera captures these reflections, enabling the tracking of both the movement and fixation of the eyes [98]. Before starting the measurements, participants were given five minutes to adjust to the lighting conditions in the test environment. Each participant also underwent a five-point screen-based calibration procedure. The experiment was conducted using an LCD with a resolution of 2400×1900 pixels (0.27 mm pixel size) and a refresh rate of 60 Hz.

ROUND/ROUNDED TYPEFACES

Chaparral Pro	ABCČDEFGHIJKLMNOPRSŠTUVZŽ abcčdefghijklmnoprsštuvzž
FG April Trial	ABCČDEFGHIJKLMNOPRSŠTUVZŽ abcčdefghijklmnoprsštuvzž
Matilda	ABCČDEFGHIJKLMNOPRSŠTUVZŽ abcčdefghijklmnoprsštuvzž
Times New Roman	ABCČDEFGHIJKLMNOPRSŠTUVZŽ abcčdefghijklmnoprsštuvzž
Comic Sans	ABCČDEFGHIJKLMNOPRSŠTUVZŽ abcčdefghijklmnoprsštuvzž

ANGULAR/POINTED TYPEFACES

Arial Nova	ABCČDEFGHIJKLMNOPRSŠTUVZŽ abcčdefghijklmnoprsštuvzž
Nogomet	ABCČDEFGHIJKLMNOPRSŠTUVZŽ abcčdefghijklmnoprsštuvzž
Sans Forgetica	ABCČDEFGHIJKLMNOPRSŠTUVZŽ abcčdefghijklmnoprsštuvzž
Verdana	ABCČDEFGHIJKLMNOPRSŠTUVZŽ abcčdefghijklmnoprsštuvzž
Anka	ABCČDEFGHIJKLMNOPRSŠTUVZŽ abcčdefghijklmnoprsštuvzž

Figure 3. Ten typefaces selected for study.**2.4. Procedure**

The measurements with a group of university students were conducted in a quiet room with walls painted with grey matte paint in accordance with the ISO 3664 standard [99].

Due to coronavirus restrictions, we could not test children in the visual science laboratory; hence, we set up a comparable test room in their elementary school, which was a bright room with artificial lighting.

The letters of the texts that the participants read on the screen were dark on a light background (text colour: #000; background colour: #eee) in accordance with the ISO 12646 standard [100]. The participants were at a distance of $60\text{ cm} \pm 1\text{ cm}$ from the screen, in line with the recommendations of the ISO 9241-303 standard [101]. Their movements were not restricted by any method; however, they were asked to remain in a still position.

To account for the potential effects of fatigue, the texts were presented to each participant in a unique sequence created by the Latin square method. The order in which the texts were read varied for each participant, ensuring that no specific text consistently appeared at the same point in the sequence, which might have otherwise influenced the results due to fatigue. We measured the reading speed and the length of fixations for all participants during the entire reading time.

After the participants read the text on the screen, they answered an additional question to check their understanding of the text content. They had to select the correct answer from three possible alternatives. They also used two 5-point scales to rate the pleasantness (1—very unpleasant; 2—unpleasant; 3—neutral; 4—pleasant; 5—very pleasant) and perceived sweetness (1—not sweet at all; 2—slightly sweet; 3—sweet; 4—quite sweet; 5—very sweet) of the typeface used to display the text. Before rating the typefaces, participants received brief instructions to rate the typefaces based on their intuition or first association. When rating pleasantness, they were asked to consider the feeling they experienced while reading each typeface. For the sweetness evaluation, they were instructed to answer the following question: “What level of sweet taste would you assign to the shape of the letters?”.

2.5. Data Analysis

We considered the ratings of pleasantness and sweetness as subjective measures of emotional response to typefaces. Reading speed and text comprehension were analysed as indicators of reading fluency.

The data were analysed using linear mixed modelling. For each person (level-2 unit of analysis), different data were collected on ten typefaces (level-1 unit of analysis), i.e., ratings of pleasantness, ratings of sweetness, reading speed, and text comprehension. In all models, data were nested within participants. Intercepts were considered random coefficients, and slopes were considered fixed across all participants.

In the first model, we investigated the relationship between the ratings of typeface sweetness and pleasantness to ensure that higher perceived (imagined) sweetness corresponds to more pleasant feelings, as expected from the literature on cross-modal interactions. Typeface pleasantness was predicted based on typeface sweetness (entered into the model as an interval predictor, i.e., level-1 covariate; the values were centred within individuals). To account for possible differences between children and adults in the strength of the relationship between typeface pleasantness and sweetness, we also included the age group as a level-2 factor (a factor with two levels, i.e., 0—elementary school students; 1—university students) in this model.

In the second model, we analysed the relationship between the typeface shape and its perceived sweetness in different age groups to assess the cross-modal interaction between shape and taste in the perception of typography. Typeface shape (round/rounded vs. angular/pointed) and age of participants (children vs. adults) were included as level-2 factors in the model. The rating of sweetness was considered an outcome variable.

In the last two models, we analysed the relationship between the rating of sweetness and two measures of reading fluency. The sweetness of the typeface was used as a level-1 covariate, while the reading speed and text comprehension were used as outcome variables. For the text comprehension analysis, we used a mixed-effects logistic regression, as the outcome variable was binary.

3. Results

Figure 4 and Table 1 show how the ratings of the sweetness of a typeface were related to the ratings of the pleasantness of a typeface. According to the literature, we expected that typefaces rated as more pleasant would also be rated as sweeter. The results show a statistically significant correlation between the rating of the sweetness of the typeface and the rating of its pleasantness. There was a statistically significant interaction between the age group and the rating of sweetness—the relationship between sweetness and pleasantness was slightly stronger in elementary school students (children) than in university students (adults). In general, age *per se* was also a statistically significant predictor of pleasantness ratings, with children using slightly higher pleasantness ratings than adults. An inspection of the random effects in the model showed that the between-subject variance (0.02) was much smaller than the within-subject variance (1.16). The intraclass correlation coefficient was small (ICC = 0.02) and adding random intercepts did not improve the model fit significantly (LRT(1) = 1.19, $p = 0.276$). These results indicate that there was very little variation in the ratings of typeface pleasantness between individuals of the same age. On average, children rated the typefaces very similarly, as did adults. However, different typefaces were rated with significant differences in pleasantness—meaning typefaces with different shapes received varying pleasantness ratings.

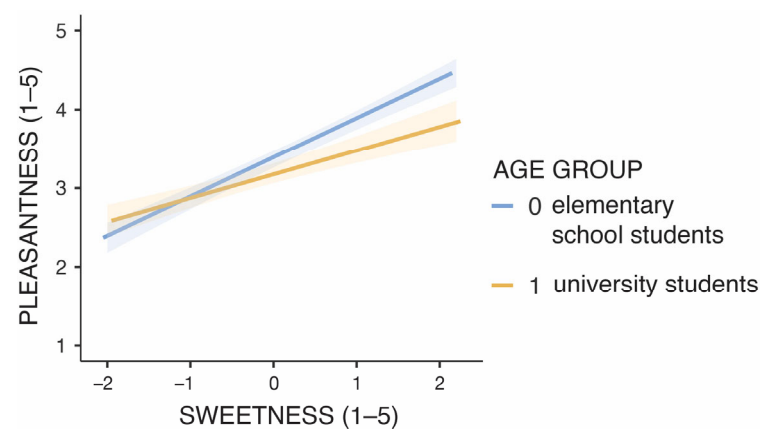


Figure 4. Effects of typeface sweetness ratings and age group on typeface pleasantness ratings.

Table 1. Fixed effects in the linear mixed model used for predicting typeface pleasantness based on typeface sweetness ratings and age group.

Source of Variability	<i>b</i>	<i>SE_b</i>	95% CI for <i>b</i>	<i>t</i>	<i>df</i>	<i>p</i>
Intercept	3.28	0.04	[3.20, 3.36]	79.17	87.9	<0.001
Typeface sweetness	0.40	0.03	[0.34, 0.46]	13.37	805.0	<0.001
Age group	−0.18	0.08	[−0.34, −0.02]	−2.15	87.9	0.034
Typeface sweetness × Age group	−0.20	0.06	[−0.31, −0.08]	−3.28	805.0	<0.001

Next, we examined the cross-modal correspondence between typeface shape and perceived taste. Adding random intercepts improved the model fit significantly

($var_{\text{between subjects}} = 0.17$, $var_{\text{within subjects}} = 1.41$, $ICC = 0.107$, $LRT(1) = 28.7$, $p = < 0.001$), indicating that the differences in sweetness ratings across individuals (e.g., due to personal preferences or individual biases) needed to be taken into account when modelling the data. The large within-subject variance nevertheless suggests that typefaces were perceived as different in their sweetness. Figure 5 and Table 2 show how typeface shape predicted readers' imagined sweetness ratings. Typeface shape and age group were found to be statistically significant factors for sweetness ratings, while no significant interaction was found between the two factors. Both younger and older readers rated round/rounded typefaces as sweeter compared to angular/pointed typefaces. In general, elementary school students rated sweetness higher than adults.

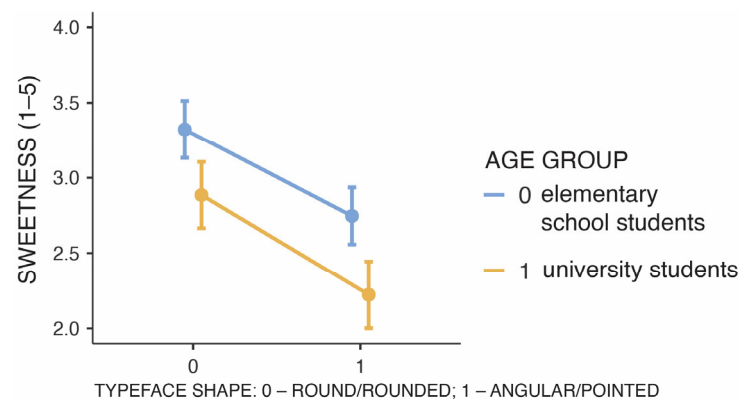


Figure 5. Effects of typeface shape and age group on ratings of typeface imagined sweetness.

Table 2. Fixed effects in the linear mixed model used for predicting typeface sweetness ratings based on typeface shape and age group.

Source of Variability	<i>b</i>	<i>SE_b</i>	95% CI for <i>b</i>	<i>t</i>	<i>df</i>	<i>p</i>
Intercept	2.79	0.06	[2.68, 2.91]	45.73	83.8	<0.001
Typeface shape	−0.62	0.08	[−0.78, −0.46]	−7.51	763.5	<0.001
Age group	−0.48	0.12	[−0.72, −0.24]	−3.93	83.8	<0.001
Typeface shape × Age group	−0.09	0.17	[−0.41, 0.24]	−0.53	763.5	0.596

Finally, we analysed the relationship between the ratings of typeface sweetness and two indicators of reading fluency in both age groups (Figure 6, Tables 3 and 4). Accounting for the between-subject differences by adding random intercepts in the model for predicting the reading speed improved the model fit significantly ($var_{\text{between subjects}} = 739$, $var_{\text{within subjects}} = 232$, $ICC = 0.761$, $LRT(1) = 913$, $p < 0.001$). There were large differences in reading times between individuals of the same age. Meanwhile, the between-subject variance in text comprehension was low ($var_{\text{between subjects}} = 0.00$, $var_{\text{within subjects}} = 1.00$, deviance = 586.1, $\chi^2/df = 1.01$, $p = 1.00$). Concerning the fixed effects in the models, there was no interaction between the age group and the sweetness of the typeface in the prediction of the reading speed (Table 3) and the prediction of text comprehension (Table 4). The relationship between the ratings of typeface sweetness and reading speed or text comprehension was therefore similar for younger and older readers. The sweetness of the typeface had a statistically significant relationship with the reading speed, an indicator of reading fluency—the sweeter the typeface, the shorter the reading time per character (Table 3, Figure 6A). The relationship between the rating of the sweetness of the typeface and text comprehension did not reach statistical significance (Table 4), although a similar trend

was observed—the higher the rated sweetness, the slightly better the text comprehension (Figure 6B). A clear and statistically significant effect of age group on both reading fluency and text comprehension was also observed—elementary school students read more slowly than university students and showed poorer text comprehension, which was to be expected as they are less experienced readers, and their cognitive abilities are less developed.

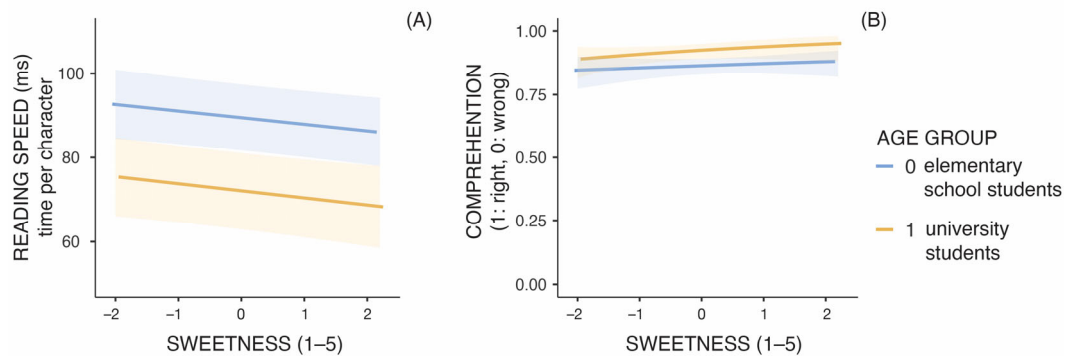


Figure 6. Effect of typeface sweetness and age group on indicators of reading fluency: (A) reading speed and (B) text comprehension.

Table 3. Fixed effects in the linear mixed model used for predicting reading time per character (in ms) based on typeface sweetness ratings and age group.

Source of Variability	<i>b</i>	<i>SE_b</i>	95% CI for <i>b</i>	<i>t</i>	<i>df</i>	<i>p</i>
Intercept	80.76	3.01	[74.86, 86.67]	26.81	84.6	<0.001
Typeface sweetness	−1.63	0.46	[−2.54, −0.73]	−3.54	773.1	<0.001
Age group	−17.59	6.03	[−29.40, −5.78]	−2.92	84.6	0.005
Typeface sweetness × Age group	−0.12	0.93	[−1.93, 1.70]	−0.13	773.1	0.900

Table 4. Results of generalised mixed modelling (with binary dependent variable) used for predicting text comprehension based on typeface sweetness ratings and age group.

Source of Variability	<i>b</i>	<i>SE_b</i>	OR	95% CI for OR	<i>z</i>	<i>p</i>
Intercept	2.19	0.13	8.90	[6.95, 11.37]	17.39	<0.001
Typeface sweetness	0.14	0.10	1.15	[0.95, 1.39]	1.46	0.14
Age group	0.67	0.25	1.96	[1.20, 3.21]	2.67	0.008
Typeface sweetness × Age group	0.14	0.19	1.15	[0.79, 1.68]	0.73	0.47

Note. OR = odds ratio.

4. Discussion

The following sections present the findings of our study, focusing on the relationship between typeface shape and reading outcomes. This research explored how cross-modal correspondences between typeface shapes and taste (specifically sweetness) influence perceived pleasantness, reading fluency, and text comprehension. This analysis was conducted across two age groups—children (elementary school students) and adults (university students)—to examine potential differences in their perception and performance.

By integrating subjective ratings (sweetness and pleasantness ratings) with objective indicators of reading fluency (reading speed and text comprehension), our study provides a more comprehensive insight into cognitive and emotional processes involved in reading. In this section, we address the role of typeface shape in facilitating reading fluency, the limitations of this study, and suggestions for future research directions.

4.1. Cross-Modal Correspondence Between Typeface Shape and Taste (Sweetness)

Typefaces of round/rounded shapes were rated as sweeter than typefaces with pointed/angular shapes. In addition, typefaces that were rated as sweeter were also rated as more pleasant for the reader. It is known that the sweet taste typically evokes pleasant feelings [81,85], as does a round or rounded shape [83–85]. Our results support the notion that shape can be associated with taste [72–76], specifically that round or rounded shapes are associated with a sweet taste, while angular or pointed shapes are associated with a bitter and sour taste [78–82]. Cross-modal correspondence between shape and taste thus also takes place in typography.

For younger readers, the correlation between the sweetness and pleasantness of the typeface was stronger than for older readers. Younger readers also rated the sweetness of typefaces higher on average than adults. The reason for these results is not clear. Several other studies have also shown that children respond to colour, shape, taste, and smell differently than adults [90,91], and that the characteristics of typefaces affect children and adults differently [59,60]. It could be that children tend to emphasise the differences between pleasant and unpleasant shapes more strongly compared to adults. It could also be that the children were more motivated to participate in our study since they were exposed to such an experimental design for the first time and they found our texts more appealing than university students who had already been exposed to such studies. The texts used in our study were taken from school textbooks and children's encyclopaedias, and the familiarity of such texts may be reflected in the ratings of pleasantness and sweetness. Further studies are needed to investigate why the children rated the typefaces as sweeter and why the association between the ratings of sweetness and pleasantness was stronger in this group.

4.2. Relationship Between Typeface Perceived Sweetness and Reading Fluency

We used two indicators of reading fluency, i.e., reading speed and reading comprehension [14,16]. Sweeter typefaces were read faster; however, no significant correlation was found between the sweetness of the typeface and text comprehension. It is possible that our comprehension test was not sufficiently discriminating. Future studies should use a better measure of text comprehension, yet this also requires longer texts, which could increase the duration of the experiment and lead to fatigue or reduced motivation to participate in the study. Nevertheless, the influence of age on text comprehension was clear enough in the present study. More experienced readers understood the texts better. They also read the texts more quickly.

From the results of our study, we can conclude that reading fluency and the emotional reactions of the reader during the reading depend on the shape of the typeface. Due to the cross-modal correspondence between different senses, some typefaces are perceived as sweeter and more pleasant than others. Since our study was a correlational study and both the emotional response and reading fluency were observed simultaneously, we cannot say with certainty at this stage whether the emotional response has an effect on reading fluency, or whether it is the other way around. This question needs to be investigated in the future using an experimental approach.

4.3. Limitations

Our research encountered several limitations that should be considered. While the texts used were of similar difficulty, there were additional factors beyond typeface shape that may have influenced the outcomes. Firstly, participants might have reacted differently to specific texts based on their interests. For instance, adults and children might show

varied emotional responses to content such as descriptions of animals. This variability could have contributed to the differences observed across age groups.

Secondly, the typefaces employed in this study varied in certain shape features that could influence reading metrics, including typographic tonal density and character size. Although the x-height was standardised, other elements such as the dimensions of ascenders and descenders differed among typefaces. This discrepancy altered the amount of white space around the ascenders and descenders, which consequently affected line spacing, even when the leading was uniformly set (at 140%). Variations in white space and the internal shapes of typeface letters inevitably led to differences in typographic tonal density, even with consistent x-height adjustments. Future investigations could focus on isolating specific features of typefaces, such as stroke shape, while controlling for all other attributes, to better understand their effects on reading.

Thirdly, the COVID-19 pandemic posed challenges to the inclusion of larger sample sizes, reducing the statistical power of our analyses. Future studies would benefit from involving more participants to strengthen the findings.

Due to pandemic restrictions, measurements with the university students were conducted in the laboratory for visual perception, whereas measurements with elementary school students were conducted on the premises of the elementary school. The differences in the experimental conditions might have affected our results. However, we made every effort to replicate the conditions of the laboratory on school premises as closely as possible to minimise differences in room illumination and, consequently, the effect of light on the readers (we ensured that the windows were covered, the lighting was artificial and uniform, and there were no surfaces that could cause glare or reflections on the computer screen; we also made sure the environment was quiet and peaceful).

Despite these limitations, we believe that our results provide valuable insights into the effect of typeface shape on reading. The study utilised multiple measures of text processing, and although the fixed effects examined were not very pronounced, the results consistently suggest that reading with round/rounded typefaces, which were perceived as sweeter and consequently more pleasant than angular/pointed ones, was smoother, more pleasant, and somewhat more effective.

These initial findings emphasise the importance of considering typeface shape and cross-modal correspondence in reading research and comparing the results of different studies. Future research is needed to corroborate these observations and to investigate the wider effects of typeface shape and cross-modal correspondence in the process of reading.

4.4. Conclusions

The present study pursued two main aims. The first one was to investigate how typeface shape influences the perceived sweetness and pleasantness of a typeface and reading fluency. Specifically, this study aimed to determine whether round/rounded typefaces are perceived as sweeter and more pleasant than angular/pointed ones and how the perception of typeface sweetness is related to reading fluency (reading speed and comprehension). The second aim was to examine differences between younger, less experienced readers and adult, more experienced readers in their responses to typeface shape. This study aimed to explore whether the relationship between perceived sweetness, pleasantness, and reading fluency varies between these two age groups.

Round/rounded typefaces were consistently rated as sweeter and more pleasant than angular/pointed typefaces. This correlation aligns with prior research suggesting that sweetness and pleasantness are often associated with rounded shapes. Interestingly, younger readers exhibited a stronger association between sweetness and pleasantness and provided higher sweetness ratings overall compared to adults.

Sweetness ratings were significantly correlated with reading speed: sweeter typefaces were read faster by both age groups. However, no significant relationship was found between sweetness and reading comprehension, likely due to limitations in our comprehension test. As expected, university students, being more experienced readers, outperformed younger students in both reading speed and comprehension.

Children displayed a greater sensitivity to typeface shape, which may be due to their heightened responsiveness to sensory stimuli, their limited exposure to typographic diversity, or their familiarity with the text materials used in this study. In contrast, adults rated typefaces with slightly lower sweetness and pleasantness, suggesting that their perceptions are less influenced by typeface design.

When evaluating emotional responses to different typefaces, the ratings of sweetness can be an adequate substitute for the ratings of pleasantness. In our study, typefaces that were rated as sweeter were read faster. Using typefaces that evoke a stronger sense of sweetness in the reader could make reading more enjoyable, which in turn could have a positive effect on the reading process for both younger and older readers. Sweeter typefaces could be recommended for the design of the reading materials for less experienced and more experienced readers. We suggest using typefaces that are not sans-serif but have more organic forms, including serif typefaces with some characteristics of old-style typefaces.

These findings reinforce the importance of considering typeface shape and cross-modal correspondences in both research and practical applications. Future studies should build on these insights to better understand the broader implications of typography for reading efficiency and enjoyment across different age groups.

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