Orthographic Processing in School-age Children - Descriptive Statistics Eye Tracking Data

Brief Introduction

Orthographic awareness (OA) — the ability to recognize and evaluate letter patterns based on the rules and regularities of a writing system —is an important component of reading development. In alphabetic languages such as English, OA supports both decoding and word recognition by enabling readers to distinguish between more and less probable letter sequences. The current study investigates orthographic processing in school-age children (grades 3–6) across three groups: children with dyslexia (n = 28), children with compensated dyslexia (n = 17), and children with typical development (TD, n = 23). By examining how these groups differ in their orthographic decision-making, the study aims to better understand the mechanisms underlying persistent and resolved reading difficulties.

To assess OA, participants completed a visual world eye-tracking task in which they were asked: **"Which word looks most like a real English word?"** Each trial presented four non-word options that varied in orthographic probability and legality:

- A high-probability (high-ortho) item resembling real English words,

- A low-probability (low-ortho) item with less typical letter sequences,

- An illegal item that violates English orthographic rules,

- An unpronounceable item with no plausible phonological form.

Participants completed 18 trials, with option locations and trial order randomized. The task was administered using E-Prime with eye-tracking data collected concurrently.

This report investigates group differences across multiple dimensions of task performance, including:

1. Accuracy, based on criteria where high-ortho or both high/low-ortho selections are considered correct,

2. Response time when selecting high-ortho and low-ortho items,

3. Eye movement metrics, such as fixation count, proportion of fixations, total dwell time and proportion of dwell time

4. The relative attention (via dwell time) given to legal vs. illegal options.

Descriptive Statistics

1. Overall Response Choices Chosen across Groups

Table 1 and Figure 1 display the raw distribution of response choices across groups. All participants met the task accuracy inclusion criterion. The final sample included 23 children with typical development (TD), 28 with dyslexia, and 17 with compensated dyslexia.

Table 1: Distribution of Response Choices by Group

Mean (SD) Number of Trials per Response Type (out of 18)

Group	High Ortho-graphic	Low Ortho-graphic	Illegal	Unpronounce-able
TD	13.61 (1.9)	4.26 (1.89)	0.13 (0.34)	0 (0)
Dyslexia	12.5 (2.32)	5.18 (1.83)	0.25 (0.8)	0.07 (0.26)
Compensated	13 (2.85)	5 (2.85)	0 (0)	0 (0)

Figure 1: Average Number of Trials Each Response Type
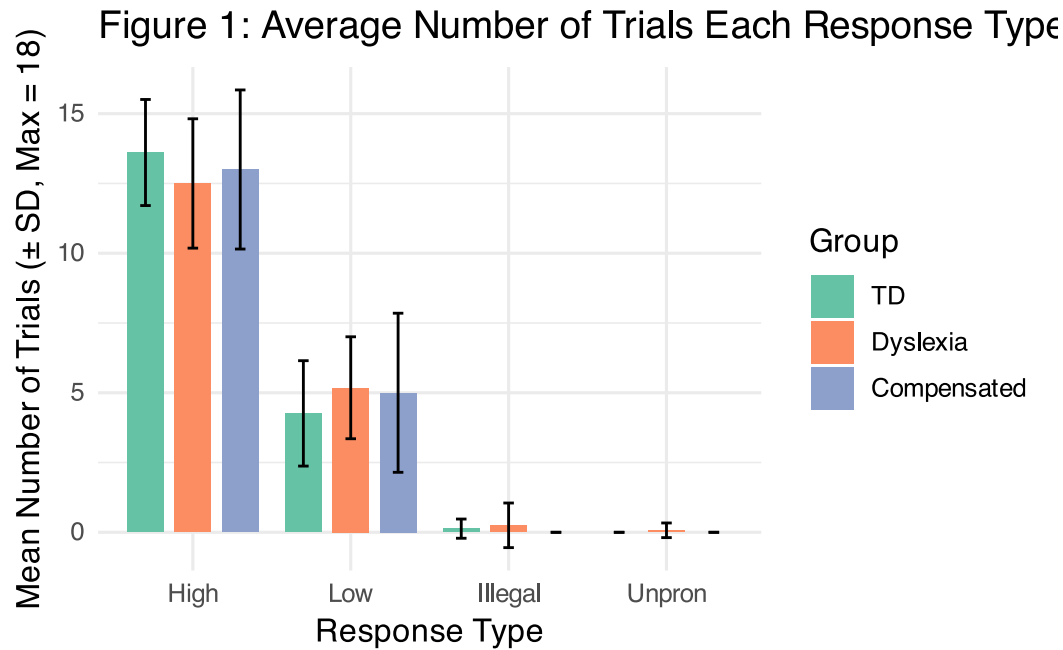
On average, participants in all three groups most frequently selected the high-orthographic probability option, with TD children choosing this option on 13.61 of 18 trials (SD = 1.90), children with dyslexia on 12.50 trials (SD = 2.32), and the compensated group on 13.00 trials (SD = 2.85). The low-orthographic option was selected less frequently, while illegal and unpronounceable options were rarely chosen.

Table 2: Two-Way ANOVA Results for High vs. Low Responses

Dependent Variable: Number of Trials per Response Type (Max = 18)

Effect	df	Sum Sq	Mean Sq	F	p
Group	2	0.58	0.29	0.06	0.94
Response Type	1	2,273.06	2,273.06	452.51	< .001
Group × Response Type	2	26.28	13.14	2.62	0.08
Residuals	130	653.02	5.02	NA	NA

Although participants had four response options (High, Low, Illegal, and Unpronounceable), the "Illegal" and "Unpronounceable" options were rarely selected across all groups. Hence, a two-way ANOVA was conducted including only the High and Low orthographic responses. The two-way ANOVA revealed a significant main effect of response type, $F(1, 130) = 452.51$, $p < .001$, indicating a clear preference for high probability orthographic words over low probability orthographic word options across groups. There was no significant main effect of group, $F(2, 130) = 0.06$, $p = .94$.

The interaction between group and response type was not significant, $F(2, 130) = 2.62$, $p = .08$, though this trend suggests potential group differences in response patterns that may warrant further investigation.

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Inclusion Criteria for Eye Tracking Analyses

The following participant-level inclusion criteria were applied to ensure reliability in all eye-tracking analyses (response time, fixation count, dwell time):

- **Task Accuracy**: Participants were required to correctly identify at least 67% of trials (≥12 out of 18), where both high and low orthographic responses were considered correct.

- **Visual Engagement**: Participants needed to have at least 12 trials in which they visually fixated on all four response options (i.e., no fixation count of zero across any of the four interest areas).

This initial inclusion ensured that participants understood the task and were visually engaged with the stimuli.

Additional Inclusion for Specific Analyses

For analyses focused on **response time** and **eye movement measures** based on "High-ortho" response selections, the following **additional criteria** were applied:

- **Participant Inclusion**: Participants were required to have **at least 10 trials** in which they selected the **"High"** orthographic response.

- **Trial Inclusion**: Only trials in which the participant selected the **"High"** option were retained for analysis.

These additional filters ensured that group comparisons were based on a sufficient number of consistent "High" responses per participant, enabling more stable and interpretable estimates of response time and eye-tracking metrics.

A total of 66 participants met the initial eye-tracking inclusion criteria (TD: n = 22, Dyslexia: n = 28, Compensated: n = 16). Further, based on the additional criteria, a final sample of 58 participants (TD: n = 22, Dyslexia: n = 22, Compensated: n = 14) were included.

Only trials where "High_Ortho" was selected were part of the analyses. Each participant contributed between 10 and 17 trials, resulting in a total of 751 trials (TD = 283, Dyslexia = 281, Compensated = 187). Table 2 presents the five-number summary of included trials per participant by group.

Table 2: High-Ortho Trials per Participant

Five-number summary of included trials per participant by group

Group	Min	Q1	Median	Q3	Max	Mean
Compensated	10.00	11.25	13.00	15.00	17.00	13.36
Dyslexia	10.00	11.00	13.00	14.00	17.00	12.77
TD	10.00	11.00	13.00	14.00	17.00	12.86

2. Response time (RT) when High_ortho is selected

Response times were analyzed for trials in which participants selected the "High" probability orthographic non-word. Descriptive statistics by group are presented in Table 3.

Table 3: Participant-Level Response Time Summary (Pre-Winsorization)

Each participant's mean RT (in seconds) before winsorization

Group	n	Mean	SD	Min	Q1	Median	Q3	Max
Compensated	14	5.42	1.69	3.04	4.43	5.10	6.21	8.45
Dyslexia	22	6.23	1.03	4.57	5.56	6.17	6.70	8.36
TD	22	5.96	2.03	2.95	4.41	5.90	7.25	10.02

Response times were converted from milliseconds to seconds. On average, the Compensated group responded slightly faster (M = 5.41 s, SD = 2.61) than both the Dyslexia (M = 6.16 s, SD = 2.36) and TD (M = 6.03 s, SD = 3.14) groups. Median response times followed a similar pattern, with the Compensated group showing the shortest median latency (4.84 s), compared to Dyslexia (5.60 s) and TD (5.30 s).

A visual inspection of the raw response time data (Figure 2) revealed a small number of unusually long trials (e.g., exceeding 20 seconds), which could reflect momentary task disengagement or other non-task-related factors.

Figure 2: Raw Response Times for High-Orthographic Tri
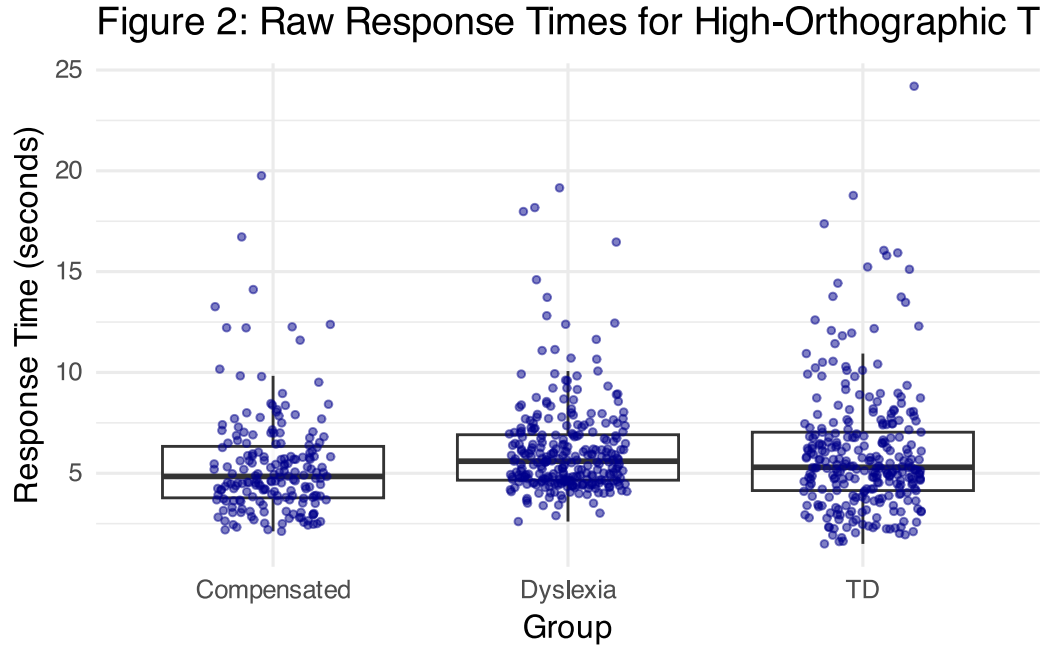
To reduce the influence of outlier trials, response times were Winsorized at the trial level using the 2.5th and 97.5th percentile thresholds. Each participant's mean response time was then computed from their Winsorized trial-level data. These participant-level means were summarized by group (Table 4). The Compensated group again showed the fastest average response (M = 5.38 s, SD = 1.60), followed by the TD group (M = 5.88 s, SD = 1.84) and the Dyslexia group (M = 6.17 s, SD = 0.94). The distributions of Winsorized trial-level response times are shown in Figure 3.

Table 4: Winsorized Participant-Level Response Time Summary

Each participant's mean RT calculated after trial-level winsorization (in seconds)

Group	n	Mean	SD	Min	Q1	Median	Q3	Max
Compensated	14	5.38	1.60	3.05	4.43	5.10	6.21	8.11
Dyslexia	22	6.17	0.94	4.57	5.56	6.17	6.70	8.09
TD	22	5.88	1.84	3.17	4.41	5.90	6.96	9.51

Figure 3: Winsorized Response Times for High-Orthographic T
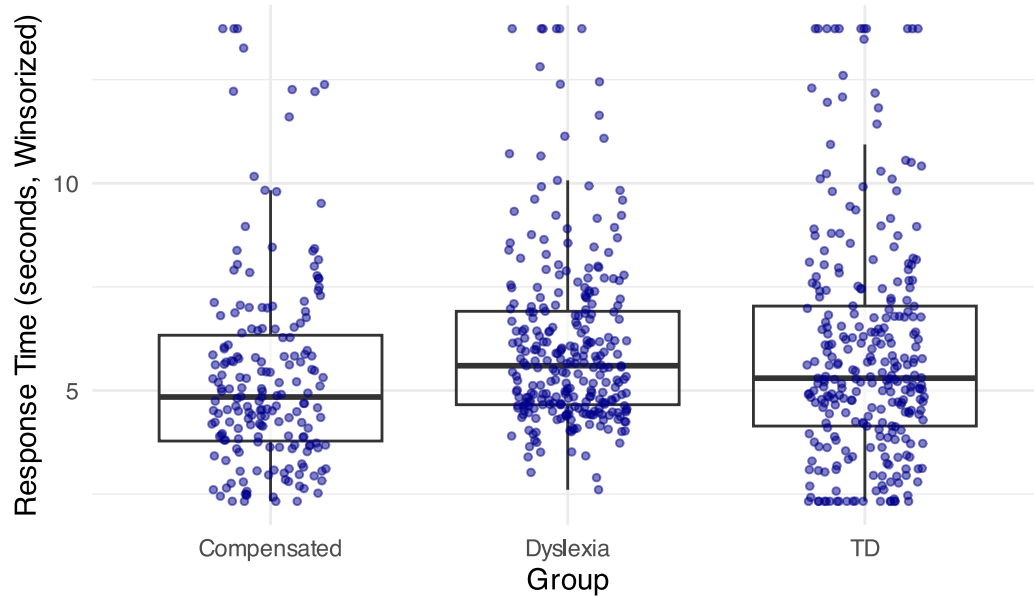
3. Eye Tracking Analyses - Fixation Count

Table 5 and Figure 4 enumerate the mean (SD) number of fixations per response option type by group.

Table 5: Number of Fixations on Each Option Type

Mean (SD) Fixation Count by Group and Item Type

Group	High Ortho	Illegal Ortho	Low Ortho	Unpronounceable Ortho
Compensated	3.63 (1.77)	1.98 (1.21)	2.69 (1.68)	1.9 (1.07)
Dyslexia	3.7 (1.73)	2 (1.12)	2.85 (1.68)	1.83 (1.03)
TD	3.81 (1.87)	2.09 (1.41)	2.68 (1.65)	1.84 (0.99)

On average, participants fixated more on the High probability orthography option than on the Low, Illegal, or Unpronounceable options across all groups. The TD group showed the highest mean fixations on High probability orthographic items (M = 3.81, SD = 1.87), followed closely by the Dyslexia (M = 3.70, SD = 1.73) and Compensated (M = 3.63, SD = 1.77) groups.

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Figure 4: Mean Number of Fixations by Response Option Type
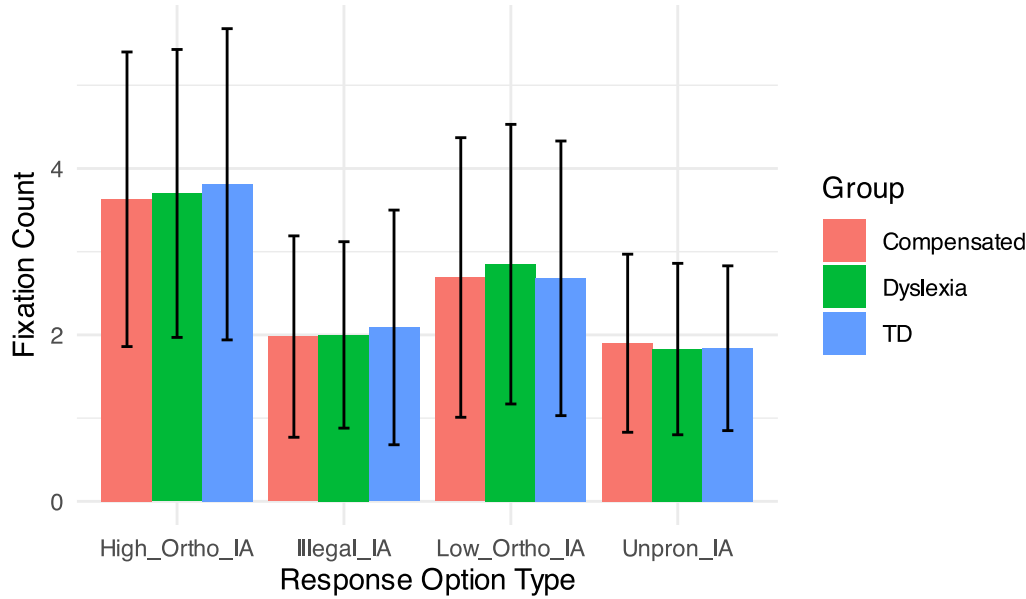
4. Eye Tracking Analyses - Fixation percentage

Table 6 and Figure 5 display the proportion of fixations allocated to each response option type, averaged across all included trials and participants within each group.

Participants in all three groups spent a similar proportion of their total fixations on the High orthographic item (M = 0.31 for all groups), suggesting consistent attention to the selected target. Fixations were distributed similarly across the other options, with the Low orthographic item receiving more fixations (M = 0.22–0.23) than the Illegal (M = 0.17) or Unpronounceable (M = 0.15–0.16) options.

Table 6: Proportion of Fixations on Each Option Type

Mean (SD) Participant-Level % Fixation by Group and Item Type

Group	High Ortho	Illegal Ortho	Low Ortho	Unpronounceable Ortho
Compensated	0.31 (0.03)	0.17 (0.01)	0.22 (0.02)	0.16 (0.01)
Dyslexia	0.31 (0.04)	0.17 (0.02)	0.23 (0.03)	0.15 (0.02)
TD	0.31 (0.04)	0.17 (0.03)	0.22 (0.03)	0.15 (0.01)

Figure 5: Participant-Level % Fixations by Response Op

Each point represents a participant's average across High-Ortho
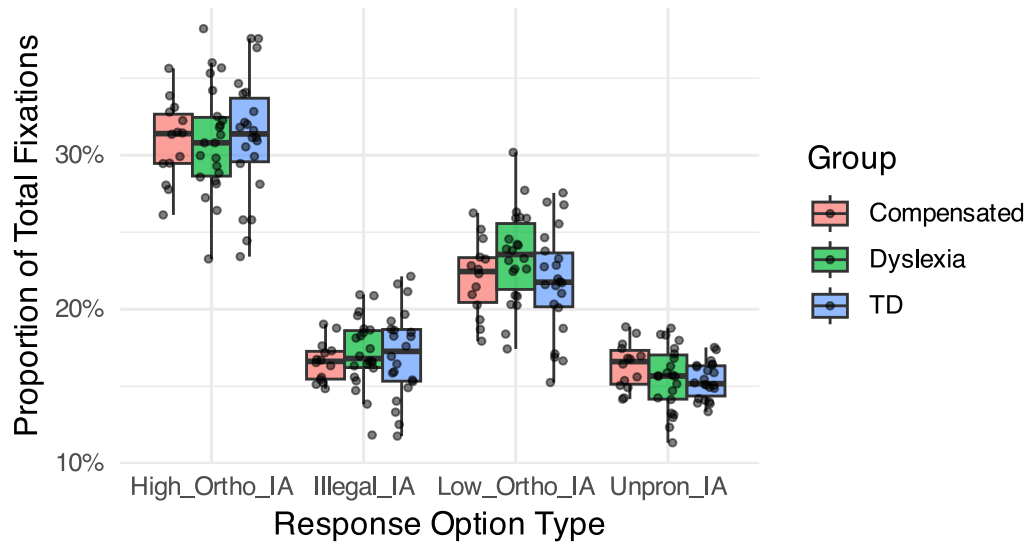
5. Eye Tracking Analyses - Dwell Time

Table 7 shows the mean (SD) dwell time in seconds for each response option type, averaged across all trials and participants within each group. On average, participants spent the most time fixating on the High probability orthographic item (M = 2.31–2.69 seconds), followed by the Low probability orthographic option (M = 1.25–1.53 seconds). Dwell time on the Illegal and Unpronounceable options was considerably shorter across all groups, ranging from 0.54 to 0.72 seconds. This pattern mirrors the fixation count results and suggests that participants not only fixated more often on orthographically plausible options, but also dwelled longer on them.

Table 7: Dwell Time on Each Option Type

Mean (SD) Dwell Time in ms by Group and Item Type

| Group	High Ortho	Illegal Ortho	Low Ortho	Unpronounceable Ortho
Compensated	2.31 (1.04)	0.64 (0.51)	1.31 (1.15)	0.62 (0.52)
Dyslexia	2.69 (1.06)	0.72 (0.57)	1.53 (1.2)	0.65 (0.5)
TD	2.69 (1.52)	0.69 (0.7)	1.25 (1.05)	0.54 (0.44)

Figure 6 displays the distribution of trial-level dwell times (in seconds) for each response option type, separated by group. Each violin plot represents the density of dwell durations for the High, Low, Illegal, and Unpronounceable orthographic nonwords.

Across all groups, dwell times were longest on the High probability orthographic items, followed by Low probability orthographic items. Illegal and Unpronounceable options consistently received shorter dwell times. The distribution of dwell times was relatively symmetric and centered around 2–3 seconds for High orthographic items, though a small number of trials extended beyond 7–8 seconds.

Overall, the dwell time distributions align well with the fixation count and percentage patterns, suggesting participants spent more time visually attending to orthographically plausible items regardless of whether they were selected or not.

Figure 6: Trial-Level Dwell Time by Response Option Type

Each dot represents a trial; dwell time shown in seconds
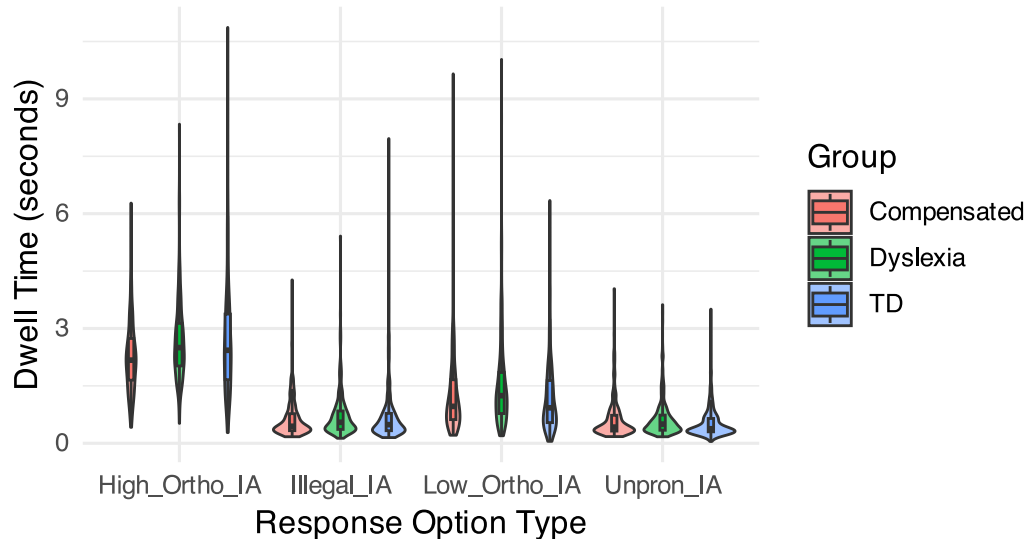
To mitigate the influence of outlier trials, dwell time data were Winsorized at the 2.5th and 97.5th percentiles at the trial level. Each participant's mean dwell time was then calculated separately for each response option type. These values were summarized by group and are presented in Table 8.

Participants in all groups exhibited the longest dwell times on the High probability orthographic options.

Figure 7 displays the distribution of Winsorized dwell times at the trial level for each response option. The same pattern was observed: participants dwelled longer on orthographically plausible items, particularly the High and Low options, with relatively short durations on the Illegal and Unpronounceable alternatives. The distributions also appear more compact after Winsorization, with fewer extreme values and more consistent ranges across groups.

Figure 7: Winsorized Trial-Level Dwell Time by Response

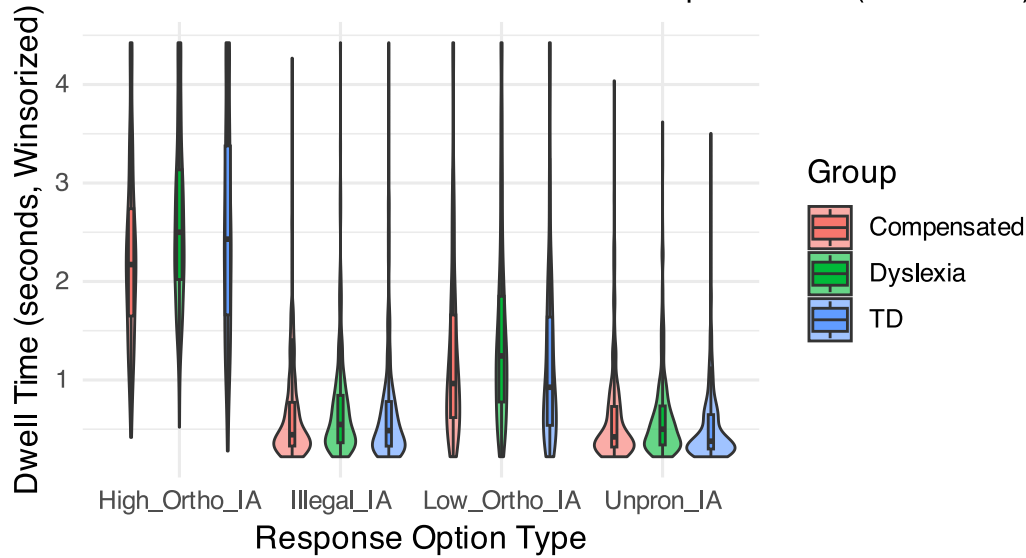Dwell time winsorized at 2.5th and 97.5th percentiles (in seconds)

Table 8: Winsorized Participant-Level Dwell Time Summary

Each participant's mean dwell time (in seconds) after trial-level winsorization

Group	High Ortho	Illegal Ortho	Low Ortho	Unpronounceable Ortho
Compensated	2.29 (0.54)	0.64 (0.29)	1.25 (0.42)	0.62 (0.28)
Dyslexia	2.63 (0.41)	0.72 (0.25)	1.49 (0.31)	0.65 (0.15)
TD	2.52 (0.75)	0.67 (0.23)	1.22 (0.53)	0.53 (0.17)

6: Eye Tracking Analyses - First Run Dwell Time

Table 9 displays the average first-run dwell time (in seconds) for each response option type, based on participant-level means. First-run dwell time reflects the amount of time participants spent looking at an item during their first pass before moving their gaze elsewhere.

Participants consistently dwelled the longest on the High probability orthographic options. Dwell times on the Low probability orthographic items were slightly shorter (ranging from 0.56 to 0.63 seconds), and the shortest dwell durations were observed for Illegal and Unpronounceable items across all groups.

Figure 8 shows the distribution of trial-level first-run dwell times. Although most data fall within a narrow range, a small number of longer trials (>2.5 seconds) are evident, especially for the High and Low options.
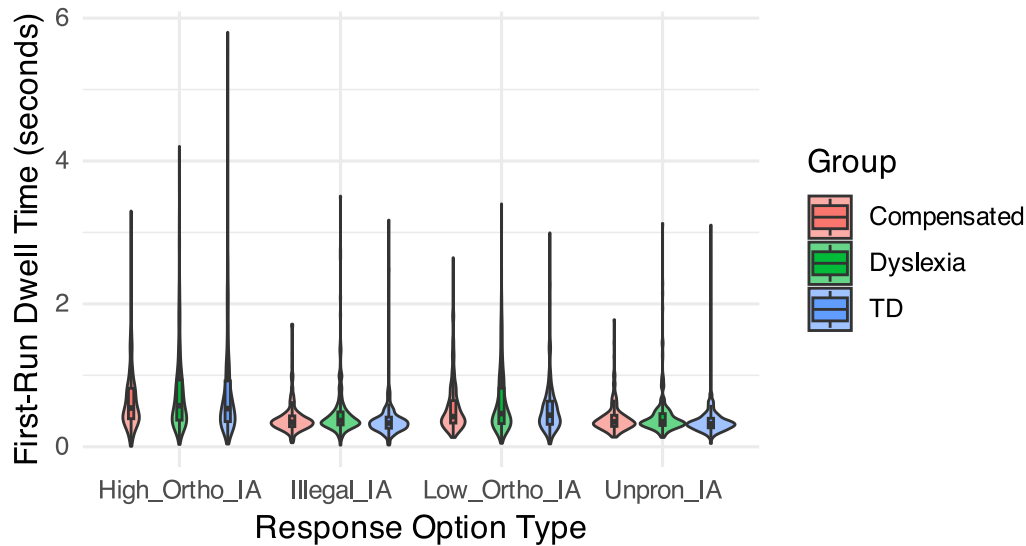
Table 9: Participant-Level First-Run Dwell Time

Each participant's mean first-run dwell time per IA (in seconds, raw)

Group	High Ortho	Illegal Ortho	Low Ortho	Unpronounceable Ortho
Compensated	0.68 (0.13)	0.4 (0.1)	0.56 (0.13)	0.4 (0.09)
Dyslexia	0.8 (0.31)	0.48 (0.19)	0.63 (0.26)	0.44 (0.1)
TD	0.8 (0.32)	0.39 (0.14)	0.56 (0.21)	0.36 (0.09)

Figure 8: Trial-Level First-Run Dwell Time by Response O

Unwinsorized first-run dwell time shown in seconds

To address the influence of potential outlier trials, first-run dwell times were Winsorized at the 2.5th and 97.5th percentiles at the trial level. Each participant's mean dwell time during their first pass over each response option type was then computed, and group-level summaries are presented in Table 10.

The pattern of results remained consistent with the raw data. Participants spent the most time on High orthographic options, with average dwell times ranging from 0.66 seconds (SD = 0.13) in the Compensated group to 0.74 seconds (SD = 0.27) in the Dyslexia group. Low orthographic items elicited shorter first-run dwell times, followed by Illegal and Unpronounceable options. Across all groups, dwell time was shortest for Unpronounceable options, with means ranging from 0.36 to 0.43 seconds.

Figure 9 shows the distribution of Winsorized first-run dwell times at the trial level. Compared to the raw data, the Winsorized distributions are more compressed, particularly for High and Low orthographic options, but still reflect the same relative differences in processing time across item types.
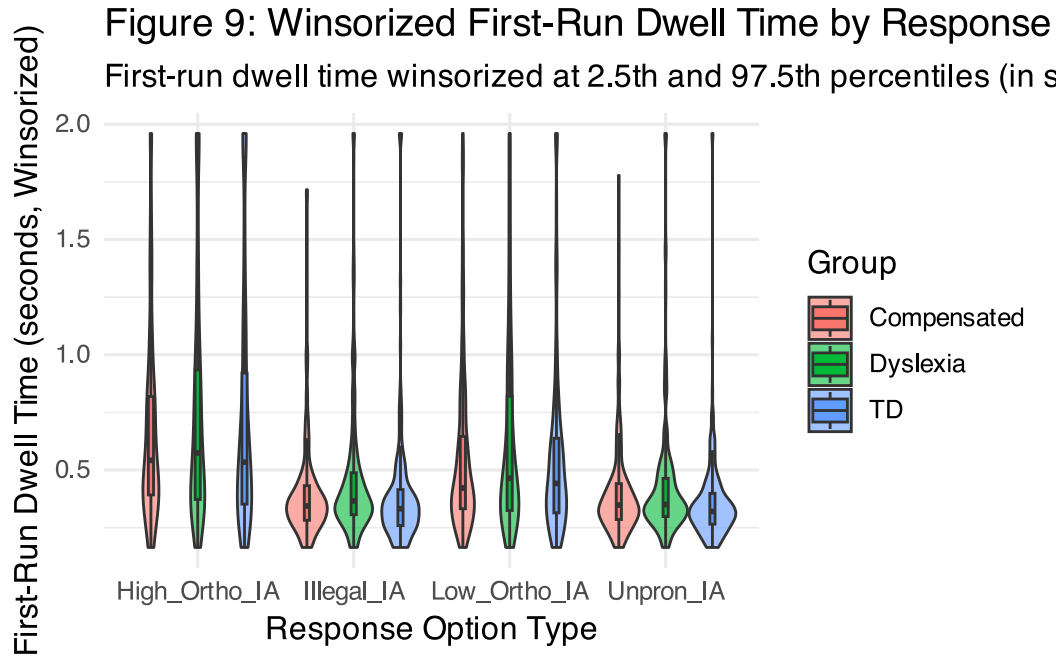
Figure 9: Winsorized First-Run Dwell Time by Response

First-run dwell time winsorized at 2.5th and 97.5th percentiles (in s

Table 10: Winsorized Participant-Level First-Run Dwell Time

Each participant's mean first-run dwell time per IA (seconds, after winsorization)

Group	High Ortho	Illegal Ortho	Low Ortho	Unpronounceable Ortho
Compensated	0.66 (0.13)	0.4 (0.1)	0.55 (0.12)	0.4 (0.09)
Dyslexia	0.74 (0.27)	0.47 (0.16)	0.62 (0.23)	0.43 (0.09)
TD	0.73 (0.22)	0.39 (0.12)	0.55 (0.19)	0.36 (0.08)