Eye Need a HERO: Speed, Accuracy, and Eye Strain with QWERTY and HERO Keyboard Layouts

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Although gaze-based typing has recently improved due to advancements in AR/VR and built-in device cameras, important difficulties remain. It is also a vital modality for disabled users. However, typing with your eyes is more difficult than expected and feels unnatural, often causing eye strain after a short period of time. Much research has been done on eye typing with traditional QWERTY keyboards, but other layouts and their impact on eye strain have not been thoroughly explored. In this study, we report on a user study with both the QWERTY layout and the HERO layout. The HERO keyboard was specifically designed for modern touch devices to minimize finger travel time, which inspired us to determine if that translates well to eye movement. Our results show no significant difference between QWERTY and HERO with speed, error rate, frustration, learnability, and usability. However, eye strain was significantly lower with HERO.

CCS Concepts: • **Human-centered computing → Accessibility technologies**; **Empirical studies in HCI**.

Additional Key Words and Phrases: eye typing, eye gaze, eye strain, gaze, QWERTY, HERO

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1 Introduction and Background

Typing through gaze interaction has been researched for over forty years [6]. In that time, eye tracking technology has steadily improved and with those improvements the modality of interaction has steadily proliferated. Recent popular releases of virtual reality headsets, such as the Apple Vision or Holo Lens 2, especially highlight the importance of eye input during hands-free interaction [19, 22]. Despite the uses for AR/VR, gaze typing is also of critical importance for disabled users who may not have full use of their speech and motor capabilities [9, 17].

But moving from a physical keyboard to a virtual one with gaze input is a challenging task and learning curves can be steep, especially with novel keyboard layouts [6]. Typical eye typing modes of interaction involve dwell and dwell-free approaches. Dwell-based approaches require users to focus on letters for some amount of time, typically 200ms to 1000ms, before the letter is selected and the user can continue to the next one [10, 16, 17]. This is often cited as cumbersome and slow [4]. Dwell-free interaction approaches seek to minimize these issues by using other modalities, such as taps or head gestures to augment gaze input [5, 11]. Shape-based techniques, such as EyeSwipe [12] and GlanceWriter [4], take this a step further by allowing users to freely move from one letter to the next and attempt to match their movements with a word. Although dwell-free approaches are more accurate in the center of the screen, participants struggle with keys near the edges. A few researchers have also attempted to examine the impact of different keyboard layouts [18, 20]. However, these have either been variations of the QWERTY layout, such as putting the keys in alphabetical order or in a circle, or rearranging the keys based on usage patterns in the English language.

All of these solutions involve some amount of eye strain, which is caused by the excessive and unnatural movement of the eyes. This is because the eyes are not a motor control organ, like the hands, but rather are a sensory organ and are typically used to scan and assess feedback in the world [24]. Although the QWERTY keyboard is the most frequently studied layout due to its familiarity, it was not designed for gaze input. Instead, it was designed for the typewriter to prevent typing arm jams by spreading out letters that are frequently used together. This is also highly effective at dual-hand input because two keys can be pressed by fingers on two hands nearly simultaneously. However, the result of putting frequent combinations on opposite sides of the keyboard is a high amount of strain for users typing with their eyes as it involves many trips across the keyboard over and over again. Eyes typically move to the center of the screen in what is known as the centrality bias, which causes further non-essential trips across the keys [18]. A recent survey of eye tracking literature that examined over 400 papers over the past 46 years found that eye strain is rarely evaluated when studying novel gaze-based typing interfaces and absent from discussions of the usability of these systems [7].

In this paper, we examine the speed, error rate, frustration, learnability, usability, and eye strain using dwell-based gaze input with two different keyboard conditions: QWERTY and HERO. The HERO keyboard was specifically designed for modern touch devices to minimize finger 'travel time' with a circular design that has the most commonly used keys closer to the center (see Figure 1c). The more frequent central letters are larger and therefore easier to hit according to Fitts' Law, which decreases the total distance traveled by the eyes by around 35% compared to the QWERTY keyboard [1]. We also utilize large language models for word prediction as users type, which is a common feedback mechanism [4, 6]. Our hypothesis was the decreased travel distance and better placement of keys in the HERO condition would lead to a lower error rate, increased speed, and lower eye strain when compared with the QWERTY condition. We adopt a within-subjects experimental design with 24 participants. Our research questions are:

- **RQ1:** What are the input (words per minute) and error rates for QWERTY and HERO keyboards?
- **RQ2:** How does user frustration, learnability, usability, and eye strain compare between QWERTY and HERO keyboards?
- **RQ3:** What was the user experience for eye typing with the QWERTY and HERO keyboards?

Our paper presents the following contributions:

(1) We present the first eye typing study on the HERO keyboard.
(2) We present the first eye typing study to show significant reduction in eye strain with a redesigned keyboard compared to a traditional QWERTY keyboard.

2 Methodology

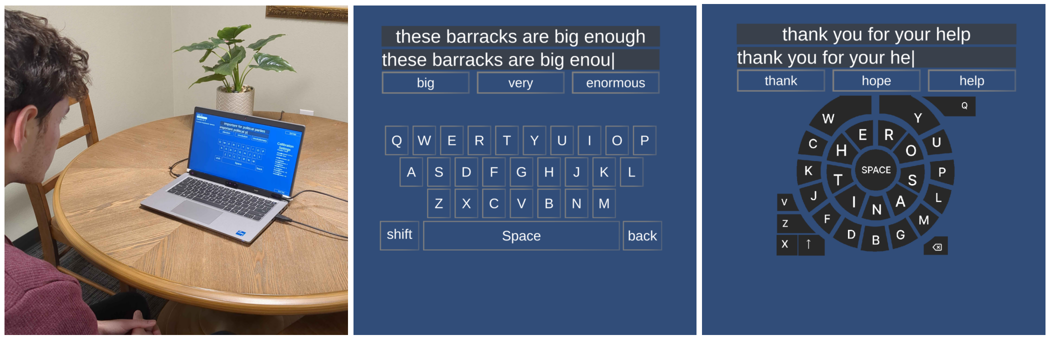
2.1 Study Design

This study was conducted at and approved by the IRB at Abilene Christian University (ACU), a small R2 university in west Texas, USA. We solicited student participation through classroom appeals in various courses, student gatherings, and mailing lists. Thirty students from various majors at ACU opted to participate and signed consent forms. However, because the HERO keyboard is only iOS-compatible, only volunteers with the ability to install it were able to participate in the study, removing six participants, and leaving us with n=24. Because users would not be familiar with the HERO keyboard, participants were required to install the HERO keyboard on their phones and use it for one week in order to familiarize themselves with the layout. Although they would not be as familiar with the HERO keyboard as they would be with the QWERTY keyboard, we attempted to mitigate this limitation through the one week requirement. Participants were required to sign up for two separate 45-minute sessions with two days separation between. We chose this to mitigate potential eye strain by giving participants time to rest their eyes between sessions.

Our study design follows Cui et al. [4] and uses a within-subjects design where participants were asked to input the same set of phrases using two different keyboards. In order to reduce learning bias we implemented a counter-balanced design by dividing participants into two groups: (1) QWERTY then HERO (n=16), and (2) HERO then QWERTY (n=8). Differences in group sizes were due to recruitment and solicitation and although we attempted to achieve the same size for both, previous studies have had 2 [13], 3 [2], 5 [21], 10 [12], and 12 [4, 8] participants. Therefore, we felt that 8 participants in the second group was acceptable. The phrases users typed were randomly selected from previous work [15] and also used by Cui et al. Before the experiment, each participant was assigned a number for future de-identification with some numbers skipped to further obfuscate their identities.

2.2 Implementation and Data Collection

We used a Dell Inspiron 5000 14-inch laptop with a screen resolution of 1920x1080 for this study. The Tobii Spark Pro eye-tracker was placed on the laptop, where the user could look at the text without changing their position. We developed our own eye tracking keyboard software using the Tobii SDK for gaze data in combination with the Unity Game Engine for a custom interface (see Figure 1). The SDK provided real-time on-screen gaze coordinates which were processed within the system as movements (saccades) or key presses (fixations over 400ms). Participants were given prompts from a diverse list of sample sentences. Various metrics were tracked as users were typing including typing performances, prompt-specific data, and aggregate data. The system also recorded detailed data about user interaction



(a) (b) (c)

Fig. 1. (a) one of the researchers entering phrases with the system in QWERTY condition in debug mode, (b) The design of the interface in the QWERTY condition, (c) The design of the interface in the HERO condition.

such as individual keypresses and prediction events. The collected data was structured and exported as a JSON file for analysis. Both keyboards shared the same codebase, visual style, and fonts. Finally, previous work developed a predictive text model using statistical models and suggested that future work utilize more advanced stochastic models [4]. Therefore, we implemented predictive text via API calls to Llama 3.2b and presented the top three candidates to users under the sentence they were typing (see Figure 1b and 1c). Multiple prompts were tested before finding one that gave the fewest errors and best suggestions. The prompt itself was quite long and contained instructions, examples, common abbreviations, and acronyms.

After each session, we collected the following data from participants via a Google Form:

(1) (a) For QWERTY condition: (Scale: 1-Strongly Disagree…5-Strongly Agree) I spend a lot of time texting or typing on a normal QWERTY keyboard.
    (b) For HERO condition: (Scale: 1-Strongly Disagree…5-Strongly Agree) I spent a lot of time last week using the HERO keyboard.
(2) (Scale: 1-Not Frustrated At All…7-Very Frustrated) Please rate your level of frustration with this eye-tracking keyboard.
(3) (Scale: 1-Strongly Disagree…7-Strongly Agree) This eye-tracking keyboard was easy to learn.
(4) (Scale: 1-Strongly Disagree…7-Strongly Agree) This eye-tracking keyboard was easy to use.
(5) (Scale: 1-No Strain, 2-Low Strain, 3-Moderate Strain, 4-High Strain, 5-Very High Strain) Please rate the level of eye strain you experienced by the end of this session.
(6) Open-ended: How would you describe your experience using this eye-tracking typing interface?

2.3 Procedure

The proctor was present when a participant arrived at the study space and once settled they reviewed the rules of the experiment together before beginning. After the participants were reminded of the study goals and risks, they were informed that they were in no way obligated to participate and that if they desired, could withdraw from the study at any time. After the introduction, the proctor assisted the participants in the calibration of the Tobii Pro Spark eye tracking hardware using the provided Tobii Pro Eye Tracker Manager calibration software. Once the eye tracking system was calibrated the proctor set a 40-minute timer and the participant was instructed to start the eye-typing experience. The participant, prompted by the system, completed 20 phrases randomly selected from a list of 500 well-known phrases from previous work [15]. The participants worked through each phrase, and upon completion, a new prompt would appear. All input from the participant was recorded, including characters, spaces, and backspaces. Once they finished the twenty phrases, or the 40-minute timer ran out, the proctor asked them to complete the survey detailed above.

2.4 Analysis

Following the study, all the data from the system during sessions were fed through a Python script that took the JSON output and determined some descriptive statistics. The script calculated wpm (words per minute) [14] and corrected the error rate [23] for each keyboard and task. Corrected Error Rate (CER) is calculated using the following formula: CER = (Number of Corrections / Total Keystrokes) x 100%. A correction is defined as any time the user backspaces and removes and replaces an input. We also calculated the error rate per key for each keyboard. All this data was then output to an Excel spreadsheet for viewing. Three researchers manually reviewed this data to check for errors in the output. We then performed a variety of statistical tests on the data, which we discuss below in Section 3.

Finally, five researchers worked together to perform a thematic analysis on the open-ended data following Clarke and Braun [3]. The first step in this process was to gain familiarization with the data by reading through all of the responses and making notes about potential codes. Then, the group discussed their initial codes and examples so that the researchers could begin creating themes. Finally, the researchers went back through the data again and placed themes on the participant responses. Sometimes a response could have multiple themes as it mentioned several ideas, topics, or feelings. During this final process, the themes were further refined as needed.

3 Results

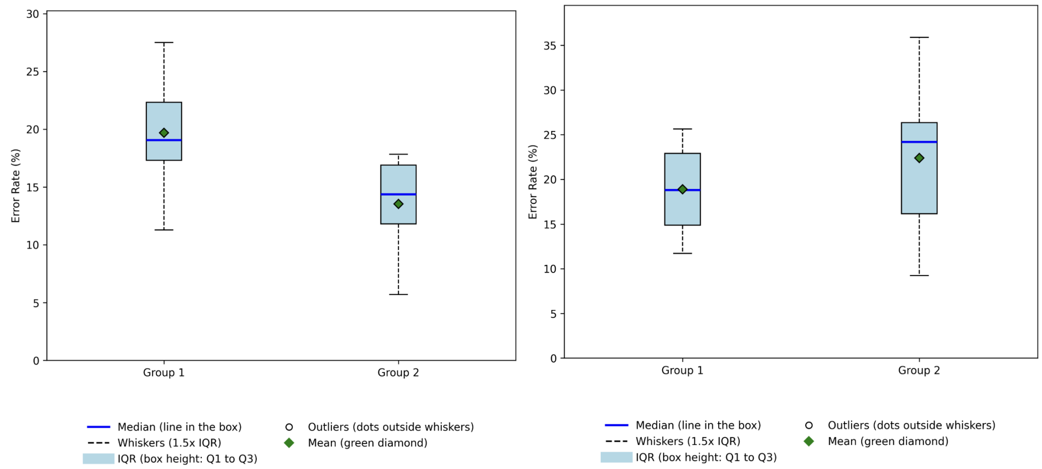
We performed a Mann-Whitney U test to compare error rates between Group 1 QWERTY and Group 2 QWERTY ($U=110$, $p=0.003$) and then also compared Group 1 HERO and Group 2 HERO ($U=0.19$, $p=0.19$). This showed that participants encountered more errors when they had to use QWERTY first than when they used it second, but no such difference occurred between groups using HERO (see Figure 2).

We also performed two way mixed ANOVA tests to confirm this finding where error rate was the dependent variable. Our results found that the order in which the keyboards are used has a significant impact on performance ($F = 25.22$, $p < 0.001$). However, there were no significant findings when comparing time spent in each session. These results validated the counter-balanced design of the study to offset learning bias in keyboard ordering.

In the remainder of this section, we compare the data between QWERTY and HERO conditions across all participants in both groups according to our three research questions.

3.1 RQ1: Time Per Task, Words Per Minute, and Error Rates

We checked the per-key error rates and time per task between QWERTY sessions and HERO sessions with a Shapiro-Wilk normality test and found that the data are not normally distributed. Therefore, we chose to use a Wilcoxon signed rank test with continuity correction on these data. For time per task (seconds to type a sentence), the means were 93.83 for QWERTY and 134.70 for HERO. Despite these differences in mean, a Wilcoxon signed rank exact test found that there was no significant difference between them ($V = 187$, p-value = 0.1424). For words per minute, the mean for QWERTY was 4.21 and the mean for HERO was 3.50. A Wilcoxon signed rank exact test found that there was no significant difference between them ($V = 77$, p-value = 0.06). The mean CER for HERO was 11.69 and for QWERTY it



(a) (b)

Fig. 2. Mann-Whitney U test comparing error rates in (a) Group 1 QWERTY to Group 2 QWERTY (U=110, p=0.003), (b) Group 1 HERO to Group 2 HERO (U=0.19, p=0.19).

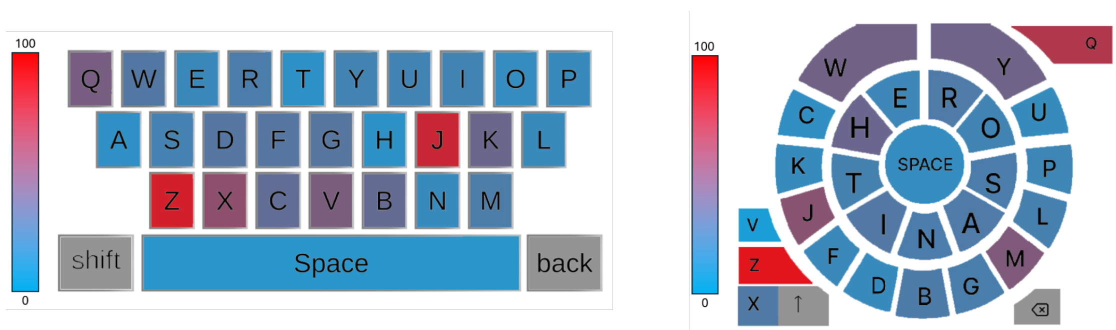


Fig. 3. The error rate as a percentage, where blue colors indicate less error and red indicates more error.

was 13.61. Wilcoxon signed rank test revealed there was no significant difference between them (V = 202, p-value = 0.7676). Figure 3 shows the error rates as a percentage on each of the keys for both keyboard layouts, visualized as a spectrum from blue (low error rate) to red (high error rate).

3.2 RQ2: Frustration, Learnability, Usability, and Eye Strain

Participants reported frustration, learnability, and usability on a 7-point Likert scale. They reported eye strain on a 5-point Likert scale with anchors to add meaning to each one. We also chose to use Wilcoxon signed rank test with continuity correction on the Likert scale data because it is ordinal. The average frustration score for QWERTY was 4.2 and for HERO was 4.04, which was not statistically significant (V = 117, p = 0.66). The average learnability score for QWERTY was 5.2 and for HERO was 5.0, which was not statistically significant (V = 64, p = 0.48). The average usability score for QWERTY was 3.5 and for HERO was 4.2, which was not statistically significant (V = 52, p = 0.08). Finally, the

	Inaccurate Eye Position	Predictive Text Bad	Fixation Time	Mental or Eye Fatigue	Bad UI	Frustrating	Easier with Time	HERO Preferred	QWERTY Preferred
Total QWERTY	5	5	5	8	5	6	3	1	4
Total HERO	9	1	5	0	4	5	2	10	3

Table 1. Results of the thematic analysis presented as the number of unique participants who were tagged with each theme, broken down by condition.

average eye strain score for QWERTY was 5.125 and for HERO was 4.125, which was statistically significant ($V = 179$, $p = 0.005$).

3.3 RQ3: User Experience

The results of the thematic analysis are presented in Table 1. This reveals some interesting trends, but mainly that users talked about their frustrations with either system after using it. Some users in both groups were unhappy with the eye position on the screen, inaccuracies in predictive text, the UI, or voiced general frustrations. Space restrictions preclude us from sharing representative quotes from each theme. Instead, below we focus on eye strain since there was a statistically significant difference between the two conditions and on what users said when they voiced preference for one condition over the other.

While none of the users in the HERO condition mentioned eye strain in their open responses, there were many in the QWERTY condition, such as this quote from P33:

> *"The eye tracking seemed to be much easier to use and matched the letters where I was looking. However, I did notice my eyes were more strained and felt very dry partway through the session. Especially after, I could feel the eye strain." (P33)*

P20 also mentioned this theme in their open response after the QWERTY condition, specifically linking it to the act of eye typing, rather than difficulty learning:

> *"Tedious and cumbersome. Not necessarily because of issues when changing something the brain is used to, but because the tracking was not very accurate, and trying to control my eyes was difficult." (P20)*

Users who preferred the HERO keyboard commented on increased usability for eye typing:

> *"I had an easier time with this keyboard. Everything was closer together which actually made it more helpful because I felt myself moving my eyes less. It feels like I did it faster but that could be wrong. It was helpful that the letters I used the most were in the center of the keyboard. Getting a space to type was easier, but backspace was harder." (P17)*

Users who preferred the QWERTY layout mentioned that it was more familiar, but also recognized that possibly biasing their decision:

> *"I personally preferred the QWERTY keyboard over the HERO keyboard; however, I imagine that is biased by the fact that I've been using the QWERTY keyboard all my life. If i had been used to the HERO keyboard more I imagine that I would have been able to type way faster than with QWERTY. I say that because while typing with QWERTY my movements between letters felt much slower, making my overall experience worse with QWERTY despite my familiarity with it." (P40)*

4 Discussion

Our hypothesis was that the HERO condition would be faster, have lower error rates, and lower eye strain. Our study revealed some interesting nuances about dwell-based gaze typing and partially contravened our hypothesis.

Participants in the QWERTY condition had a higher WPM (4.2) than in the HERO condition (3.5), though it was not statistically significant. Mott et al. were able to achieve 9 to 12 WPM with their cascading technique to improve dwell-based systems [17]. Majaranta et al. showed a WPM of 6.9 in the first session, but by the tenth session users were at 19.9 WPM [16]. Their first result is closer to ours and shows that speeds would possibly increase with more sessions. Hu et al. presented a table of dwell-free metrics, which showed WPM from 6.03 to 15.95 [8]. These metrics above indicate that our WPM, while on the lower end, is not far from the norm. It is not surprising that our users were able to type slightly faster with the QWERTY keyboard due to familiarity. However, users acknowledged this in their open responses and some noted that they might get better over time with more usage of the HERO layout.

Surprisingly, there was no statistically significant difference in error rates between the two conditions. In our study, the mean CER for HERO was 11.69 and for QWERTY it was 13.61. Hu et al. report on multiple studies with CER ranging from 1.19 to 16.9 [8], showing that our reported error rates are within normal ranges. As expected from prior literature, both conditions also struggled with letters at the edges of the keyboard (see Figure 3). Interestingly, there was a significant difference between groups using QWERTY, but not HERO, indicating a learning bias with QWERTY.

Among subjective measures, we found no difference in frustration, learnability, and usability between the conditions. The only subjective measure that was statistically significant was lower eye strain in the HERO condition, which we predicted in our hypothesis. This finding was supported by the thematic analysis where participants tended to mention eye strain in their open response texts after finishing the QWERTY session. However, they did not mention this after the HERO session. Given that eye strain is largely absent from empirical work on eye typing [7], it is difficult to compare our result to others. Cui et al. reported that GlanceWriter performed better than the other conditions in both physical effort and in comfort [4]. However, they did not directly link these metrics to eye strain.

Future work should examine the HERO layout with a dwell-free system, which could increase words per minute and perhaps also impact other metrics on which we reported. Future work should also run a longer study to determine if more practice with the HERO keyboard impacts speed and error rates as our users predicted.

5 Conclusion

In this paper, we presented the results from two eye tracking keyboards: QWERTY and HERO. Our results indicate that although QWERTY was slightly faster for input speed, the result was not significant and could be due to a familiarly bias. We did not find significant differences in error rate, frustration, learnability, or usability from the HERO keyboard. Moreover, participants reported significantly less eye strain after the HERO condition compared to the QWERTY condition. This indicates that a keyboard layout can directly impact eye strain without sacrificing speed or accuracy. For disabled users who utilize eye typing as their primary method of text input, a reduction in eye strain could mean large gains in overall usability.

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