Colour-coded Visual Aids for Learning Unfamiliar Virtual Keyboards

Ioulia Simou
Computer Engineering and Informatics Department
University of Patras
Rio, Greece
simo@ceid.upatras.gr

Andreas Komninos
Computer Engineering and Informatics Department
University of Patras
Rio, Greece
akomninos@ceid.upatras.gr

John Garofalakis
Computer Engineering and Informatics Department
University of Patras
Rio, Greece
garofala@ceid.upatras.gr

Abstract

Virtual keyboards are essential for mobile text entry. Yet, text entry is a learned skill that requires a significant investment in practice by novice users, or re-training when a novel keyboard layout is adopted. This study assesses the learning of unfamiliar virtual keyboard layouts, by evaluating mobile users' typing performance and accuracy under two conditions: 1) using the layouts without any assistance, 2) using the layouts with colour-coded keys as a visual aid. Our goal is to determine whether colour-coding improves the learning of novel keyboard layouts. The experiment results are analyzed to compare speed, accuracy and user experience between the two conditions. Our findings could provide valuable insights into the design of virtual keyboards, particularly in terms of visual enhancements that may improve adoption and usability and contribute to the broader discussion of improving text entry methods for touchscreen devices.

CCS Concepts

• **Human-centered computing** → **User studies**; **Touch screens**; **Text input**; **Mobile devices**.

Keywords

Text entry, Mobile Devices, Touch Screens

ACM Reference Format:
Ioulia Simou, Andreas Komninos, and John Garofalakis. 2025. Colour-coded Visual Aids for Learning Unfamiliar Virtual Keyboards. In *CHIGreece 2025: 3rd International Conference of the ACM Greek SIGCHI Chapter (CHIGreece 2025), September 24–26, 2025, Hermoupolis, Syros, Greece*. ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/3749012.3749058

1 Introduction

Text entry on touchscreen devices is a core aspect of Human - Computer Interaction (HCI), enabling users to perform everyday tasks using mobile devices. While soft keyboards are now ubiquitous, typing efficiency relies on users' familiarity with each layout. The QWERTY layout is frequently used due to users' habits, and not due to the layout being optimized for users' typing performance. Learning to type on soft keyboards is a cognitively demanding process that requires notable effort by the users. So, while previous research has shown the potential advantages of optimised layouts, users face a significant learning curve and may struggle with reaching sufficient typing and accuracy rates with alternative unfamiliar layouts, thus hindering their widespread adoption. To ease this transition, visual aids have been introduced as a strategy to support users. Even with QWERTY, learning to type can be challenging for novice learners, including children, adolescents, elderly users and less digitally literate users.

This study explores whether colour-coded visual aids can support the acquisition of novel virtual keyboard layouts, by supporting memory and spatial recognition. We compare typing performance, accuracy and user experience across two conditions, using the novel layouts with and without colour-coded keys in mobile context, and aiming to investigate how visual support influences the learning process. Our findings may contribute to the broader discussion of improving text entry methods for touchscreen devices, providing insights into potential visual enhancements on virtual keyboards that may improve adoption and usability.

2 Related Work

Before mobile devices and virtual keyboards, research examined how novice users learned to type on unfamiliar layouts [2, 5]. More recent longitudinal studies have analyzed typing speed, accuracy, and learning curves with novel layouts, such as one-handed chording keyboards [9–11]. The growing ubiquity of virtual keyboards has naturally prompted research to investigate how users performed on these interfaces. Several studies have examined how novice users learn to type on virtual keyboard layouts, tracking their performance across multiple sessions and modeling the resulting learning curves. MacKenzie and Zhang [12] introduced an optimized soft keyboard (OPTI) and found that novice users improved their typing performance across the experimental sessions following power-law trajectories, and ultimately surpassed QWERTY performance after 10 sessions. In [3], authors introduced a novel optimized touchscreen keyboard and tracked users' performance over four daily sessions, demonstrating short-term learning curves for the keyboard, along with users' performance metrics in terms of speed (WPM) and accuracy. Lately, Jokinen et al. [8] developed a model that simulated how users learned to locate keys on novel virtual keyboards and estimated user learning costs. In [14], authors explored whether repeatedly typing the same phrase could be used to estimate expert-level performance on unfamiliar layouts. While results showed short-term improvements, they indicated that this

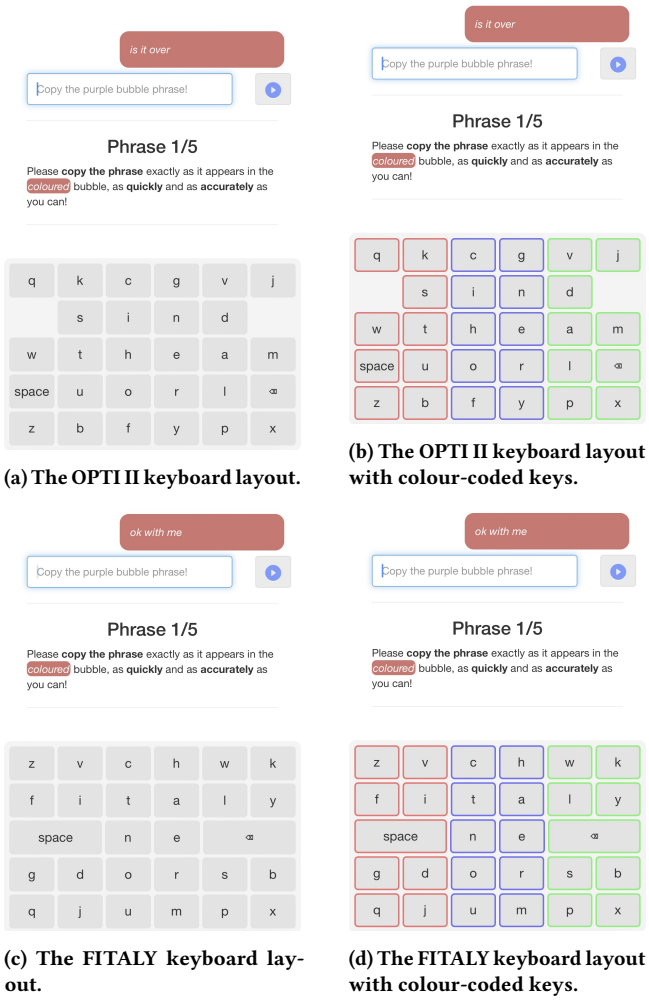
Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for third-party components of this work must be honored. For all other uses, contact the owner/author(s).
CHIGreece 2025, Hermoupolis, Syros, Greece
© 2025 Copyright held by the owner/author(s).
ACM ISBN 979-8-4007-1561-7/25/09
https://doi.org/10.1145/3749012.3749058

method could not act as a reliable substitute for long-term training when aiming to evaluate expert performance.

Previous work has explored visual cues, such as key resizing, as an attempt to enhance users' typing performance [6]. However, these studies have not evaluated whether the aids genuinely support users' learning and spatial memory, or merely assist during the active use of a keyboard. Most visual cues have been implemented as real-time support mechanisms aimed at improving input speed and accuracy, often relying on dynamic language models to predict the next likely character [4, 13]. While effective in the short term, these adaptive visual cues may introduce cognitive distractions and do not necessarily contribute to lasting layout familiarity. To the best of our knowledge, no prior studies have investigated visual aids explicitly as a learning support mechanism to help users form mental associations with key locations on unfamiliar keyboard layouts, nor have they assessed user performance after their removal.

3 System Design and Implementation

We selected two optimized virtual keyboard layouts, OPTI II [18] and FITALY [12], for our implementation. Since our participants were already familiar with QWERTY (see next section), we did not employ a randomised QWERTY-like layout as in [8], since we wanted to instill an experience of something entirely new to participants. A randomised QWERTY-like layout is a "same-but-different" type of experience, and not an entirely novel experience, which would add unnecessary confounding factors to the experiment, as users would expect to find keys in the usual locations. Our aim was to investigate whether the use of colour-coding could assist users with remembering more efficiently the positions of each letter within these novel layouts. The main hypothesis is that if users were able to learn to associate letters with colours while learning the new layout, this might reduce the search space when trying to recall the location of each key, thus enhancing their spatial memory. To this end, we divided each keyboard into three vertical keyboard zones, assigning a distinct colour to each: red (left), blue (center) and green (right). The system was developed as a responsive web application, accessible via mobile browsers at users' convenience. Both the transcription interface and the keyboards were built in Javascript, therefore the default keyboard of the users' devices is not invoked during typing and the app's keyboard dynamically adjusted to fit various screen sizes, with letter sizing scaling accordingly. Features such as autocorrect, word suggestions, and glide typing were intentionally omitted. Figure 1 illustrates the four implemented keyboard layouts used during the experimental sessions.



(a) The OPTI II keyboard layout.

(b) The OPTI II keyboard layout with colour-coded keys.

(c) The FITALY keyboard layout.

(d) The FITALY keyboard layout with colour-coded keys.

Figure 1: Visual representation of the four keyboard layouts presented to users during the experiment in the web application interface.

4 Study Design

We recruited 27 participants (age range: $18-44$, $\bar{x} = 26.04$, $\sigma = 6.04$) via convenience sampling through the students' mailing list of the local university department, staff network, and personal contacts. Ten participants identified as female and 17 as male. Educational backgrounds included high school diplomas (12), vocational diplomas (2), university degrees (9), and master's degrees (4). Participants were either students (12), employed (12), or self-employed (3). They received no specific instructions regarding typing mode (e.g. single digit, thumb or two-thumb typing) and performed the experiment remotely, using their own mobile devices, at their preferred time and location.

We employed a within-subject design. Participants were exposed to the two selected novel keyboard layouts (OPTI II [18] and FITALY [12]), performing two sessions with one keyboard, before moving on to a further two with the other keyboard. Each session consisted of 10 blocks of 5 phrases each, and were temporally separated by at least 12 hours, enforced by application logic in the experiment code, to reduce the potential influence of short-term learning effects. Sentences were drawn from the Enron Mobile Email Dataset [16] and were distribured across sessions based on their length, i.e. longer sentences were shown during the second and fourth sessions. After each session, participants completed a NASA-TLX survey, assessing their perceived workload. Each participant received colour-coded visual aids during only one layout, either in Session 1 or Session 3. Participants who received the aid in Session 1 continued with the

same layout without aid in Session 2, then switched to the other layout (no aid) for Sessions 3 and 4. Conversely, those who received no aid initially received it in Session 3, with the same layout used without aid in Session 4.

After the final session, participants completed a final questionnaire, assessing their impressions of the colour-coded keys, on four different dimensions on a 1 to 5 Likert Scale. The dimensions and the corresponding questions (adapted from [7]) were: **Perceived Usefulness**: 1) Having the colour-coded keys is very helpful for me to learn a new keyboard layout, 2) Having the colour-coded keys is more useful than learning a new keyboard just through practice, 3) Having the colour-coded keys for learning, enriches the learning activity; **Perceived Ease Of Use**: 4) Having the colour-coded keys to help with learning a new keyboard is not difficult for me, 5) I quickly learned to apply the colour-coded keys in learning a new keyboard, 6) I think the system interface with the colour-coded keys is easy to use; **Learning Motivation**: 7) I think that having the colour-coded keys makes learning a new keyboard interesting, 8) I think it is worth to apply the colour-coded keys in learning a new keyboard, 9) To me, it is important to apply the colour-coded keys in learning a new keyboard; **Learning Satisfaction**: 10) I feel very satisfied with learning a new keyboard with the colour-coded keys, 11) I think it is a wise choice to learn a new keyboard by having the colour-coded keys, 12) If I still have the opportunity to apply colour-coded keys with a new keyboard, I will be happy to do so.

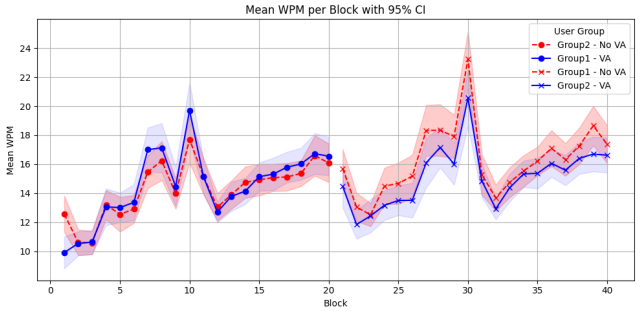
5 Results

To assess how participants adapted to the unfamiliar keyboard layouts, we analyzed key performance metrics, including Words Per Minute (WPM) [1], Interkey Interval (IKI) [17], Minimum String Distance (MSD) [15] and the number of Backspaces. These measures provide a comprehensive overview of users' speed and accuracy. We also collected subjective feedback to better understand participants' overall experience. We treated both layouts as functionally equivalent (i.e. a novel keyboard layout that needs to be learned without prior experience) and divided participants into two groups: *Group 1* received the Visual Aid during in Session 1, and *Group 2* in Session 3. Sessions were structured as follows: Session 1 (Blocks 1 - 10), Session 2 (Blocks 11 - 20), Session 3 (Blocks 21 - 30), and Session 4 (Blocks 31 - 40).

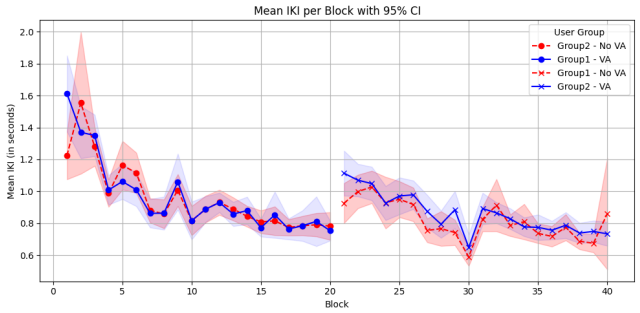
5.1 Typing Speed Metrics

To evaluate typing performance, we calculated Words Per Minute (WPM) and Interkey Interval (IKI) across the four sessions. Figures 2a and 2b display the mean WPM and mean IKI, respectively, per block for each group. In our case IKI is more important, as it better reflects visual search time and is not affected by confounding factors such as the time taken to correct typing errors. To calculate IKI, we excluded consecutive key press pairs of the same letter (e.g. 'tt'), spaces (e.g. '␣t', 't␣', '␣␣') and backspaces (e.g. '← t', 't ←', '←←'), since for double presses of the same key the target has already been located, and space and backspace keys are more easy to locate and remember compared to other keys.

Regarding WPM, Group 1 recorded a mean of $\bar{x} = 13.88WPM, \sigma = 3.53$ in Session 1, $\bar{x} = 15.13WPM, \sigma = 3.25$ in the second session



(a) Mean WPM per Block.



(b) Mean IKI per Block.

Figure 2: Typing speed metrics across blocks: (a) Words per Minute (WPM) and (b) Inter-Key Interval (IKI).

and $\bar{x} = 16.34WPM, \sigma = 3.74$ and $\bar{x} = 16.22WPM, \sigma = 3.73$ in Session 3 and Session 4 respectively. We conducted paired statistical tests to compare performance between the first and second session and between the third and fourth session. Results indicated a statistically significant improvement between the typing speeds of the first and second session ($t = -3.353, p = 0.005$), but no significant difference between Sessions 3 and 4 ($t = 0.365, p = 0.721$). Group 2 showed a similar pattern, with WPM scores of $\bar{x} = 13.58WPM, \sigma = 2.55$, $\bar{x} = 15.00WPM, \sigma = 3.30$, $\bar{x} = 14.88WPM, \sigma = 3.28$ and $\bar{x} = 15.42WPM, \sigma = 2.91$ across Sessions 1 through 4, respectively. Statistical analysis revealed a statistically significant difference during the first two sessions ($t = -3.158, p = 0.008$), but no significant change was observed between the last two sessions ($t = -1.002, p = 0.336$). Taken together, it appears that the observed improvements between Sessions 1 and 2 are likely due to initial adaptation to the unfamiliar keyboard layouts, rather than the presence of the visual aid. In other words, in Session 1, participants needed to "snap out" of their previous experience with QWERTY keyboards, which generated an impulse to look for a target, or move the finger subconsciously to the familiar location in the keyboard. This is supported by the lack of significant differences in later sessions, particularly for Group 2, which received the visual aid in Session 3. Indeed, we notice that in the 3rd session participants start with a higher WPM in the first block, compared to the first block in Session 1, despite the layout being entirely unfamiliar (Block 1: $\bar{x} = 11.20WPM, \sigma = 3.30$; Block 21: $\bar{x} = 15.11WPM, \sigma = 2.93$; $t = -5.878, p < 0.05$). While it could be assumed that at least

part of this difference is attributable to some transfer of general familiarity with the experiment structure, a closer look in participant performance at the start of Session 2 (block 11), by which participants are already familiar with the experiment structure, and Session 3 (block 21), where participants start with an entirely unfamiliar layout, shows that performance is equivalent (Block 11: $\bar{x} = 15.15WPM, \sigma = 3.92$; Block 21: $\bar{x} = 15.11WPM, \sigma = 2.93$; $t = 0.067, p = 0.947$), though we would expect their performance in Session 3 to be significantly lower. Therefore it is not the familiarity with the experiment structure that affects performance across the starting blocks in each session. The plausible explanation for this phenomenon is that by Block 21, users have already learned that they cannot rely on their experience with QWERTY, and therefore are less influenced by it while learning a new layout.

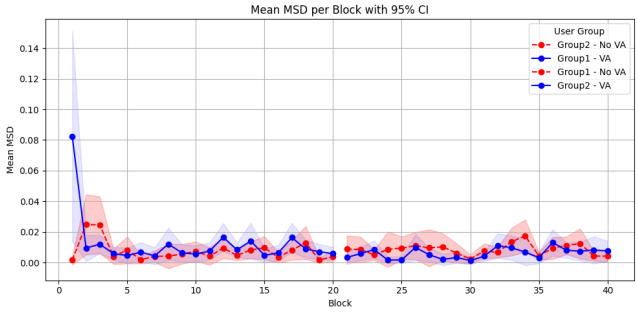
As for IKI, during the first session Group 1 recorded a mean of $\bar{x} = 1.10secs, \sigma = 0.30$ and Group 2 a mean of $\bar{x} = 1.09secs, \sigma = 0.27$. In Session 2, Group 1 had a mean of $\bar{x} = 0.83secs, \sigma = 0.25$ and Group 2 a mean of $\bar{x} = 0.83secs, \sigma = 0.23$. Group 1 had a mean of $\bar{x} = 0.86secs, \sigma = 0.24$ in Session 3, decreasing to a mean of $\bar{x} = 0.78secs, \sigma = 0.26$ in Session 4. Respectively, Group 2 had a mean of $\bar{x} = 0.93secs, \sigma = 0.24$ in Session 3, and a mean of $\bar{x} = 0.79secs, \sigma = 0.21$ in Session 4. Statistical tests confirmed significant differences across both session pairs for both groups ($p < 0.05$ for all comparisons). However, these differences could also be more plausibly attributed to users' growing familiarity with the novel layouts, rather to the timing of the visual aid. It is worth noting that both groups exhibited lower mean IKIs during Session 3, when they were introduced to the second layout, than in Session 1, suggesting the relaxation of influence from QWERTY experience, as per our WPM analysis.

5.2 Accuracy Metrics

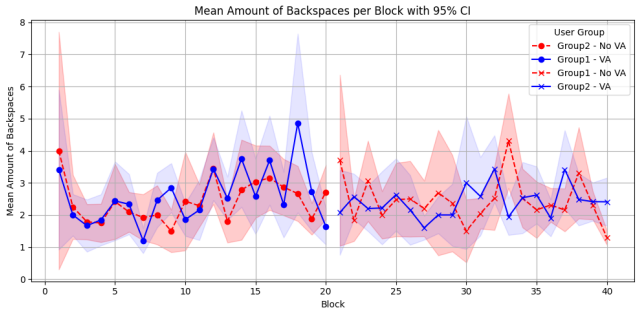
For the evaluation of users' accuracy, we computed the Minimum String Distance (MSD) and the number of Backspaces. As outlined previously, the sentences used in the second and fourth sessions were longer than those in the first and third session. To account for this, we normalized the computed Levenshtein distance between the target and submitted sentence by dividing it by the length of the target sentence. Figure 3a illustrates the normalized MSD per block, while Figure 3b presents the mean number of Backspaces per block, across all four sessions. Statistical analyses of both Minimum String Distance (MSD) and backspace usage revealed no significant differences for either Group 1 or Group 2 across all session pairs, except for a marginal effect in Group 2's MSD between Sessions 3 and 4 ($p = 0.040$). Taken in conjunction with the results for the typing speed metrics, these findings suggest that users' typing performance was not meaningfully influenced by the length of the transcribed sentences or the occurrence of errors during text entry.

5.3 Overall Experience and Perceived Workload

A final questionnaire was administered to gather qualitative insights into participants' overall impressions of the visual aid on the novel keyboard layouts. We present the responses from Group 1 and Group 2 in Figures 4a and 4b respectively, to explore potential differences based on when participants were exposed to the visual



(a) Mean normalised MSD per Block.



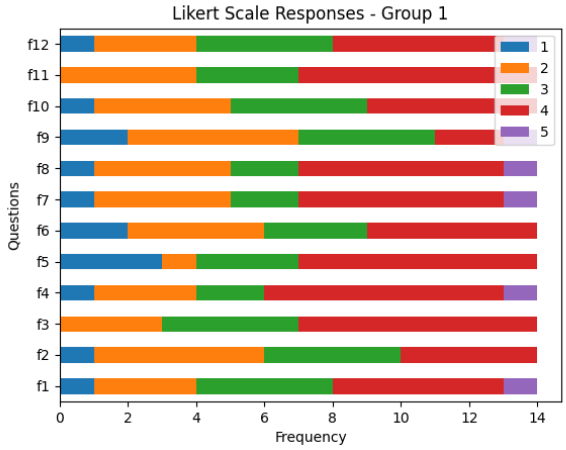
(b) Mean number of Backspaces per Block.

Figure 3: Typing accuracy metrics across blocks: (a) MSD and (b) Backspaces.

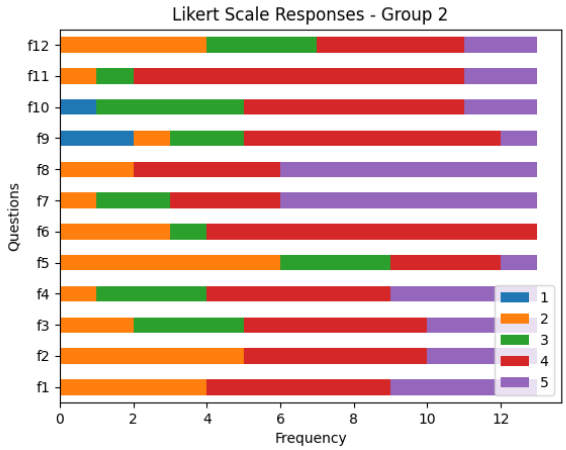
aid during the study. These suggest that participants were generally receptive to the inclusion of visual aid. Notably, users who were introduced to the visual aid in the third session rated the colour-coding assistance more positively than users who received the visual assistance in the first session. This may indicate that, once users had time to break away from the influence of the familiar QWERTY layout in order to learn an unfamiliar keyboard, they were more inclined to view the visual aid as a helpful learning support rather than a distraction. Such feedback suggests that the visual aid could be more beneficial after the initial cognitive load of adapting to a new layout has been reduced, acting as a supporting tool. Participants also completed the NASA-TLX survey after each session to assess perceived workload. Only Typing Mental Demand results showed a significant difference for Group 1 between Sessions 1 and 2 ($\bar{x} = 13.57, \sigma = 4.65$ vs. $\bar{x} = 10.21, \sigma = 4.51$; $t = 4.33, p = 0.0008$). No significant difference was observed for Group 2 between Sessions 3 and 4 ($p = 0.299$), likely reflecting the cognitive effort of transitioning away from the QWERTY layout rather than an effect of the visual aid.

6 Discussion

This study examined whether colour-coding unfamiliar keyboard layouts could support users in their learning over time. While input speed and accuracy metrics improved consistently across sessions, there was little evidence to suggest that the visual aid had a measurable effect on users' overall performance. These improvements likely stemmed from users gradually moving away from QWERTY



(a) Responses of Group 1 users.



(b) Responses of Group 2 users.

Figure 4: Final Questionnaire responses, assessing their overall experience with the Visual Aid.

familiarity and becoming more accustomed to OPTI II and FITALY layouts.

Interestingly, qualitative feedback provides a deeper perspective. Users who received the visual aid after becoming somewhat accustomed to the unfamiliar layout and experimental process (Group 2) evaluated the colour-coded keys more positively across all four measured dimensions. This suggests that the timing of introducing the visual support affects its perceived helpfulness. When introduced too early, its effect may be overshadowed by the cognitive load of adapting to a non-QWERTY layout. After an initial adjustment period, however, such visual aids may be embraced as helpful rather than intrusive. This conclusion can also be supported by the NASA-TLX data, where only Typing Mental Demand in Session 1 showed a statistically significant difference, likely reflecting the effort of initial adjustment rather than the effect of the visual aid. Taken together, our findings imply that while visual aids may not produce immediate performance benefits under high cognitive load, they could still play a significant role in supporting users' learning, by introducing a type of placebo effect that encourages participants to continue learning and to reduce frustration in the process, particularly when introduced after an initial familiarization session with the unknown interface.

Nevertheless, several limitations must be acknowledged. First, the sample primarily consisted of university students, which may limit generalizability. While participants were treated as novices with respect to the keyboard layouts used in the experiment, since participants were not familiar with them, their prior experience with virtual keyboards, particularly QWERTY, may have influenced their typing strategies and diminished the observable effect of the visual aids. As such, results may not fully reflect the experiences of truly novice users with no prior exposure to text entry using virtual keyboards. Uncontrolled variability may have also been introduced due to the remote performance of the tasks, with the use of several different personal devices, which is an inherent drawback of in-the-wild studies. Our study did not assess long-term learning or spatial memory of the keyboard layouts, limiting our ability to determine whether the visual aids contribute to durable internalization of the key positions or if their effect is short-term. Future studies should incorporate delayed follow-up sessions, with and without the aid, to assess retention and deeper spatial learning. Future research could also explore different forms of visual support beyond static colour-coded zones, such as colour-coding specific keys like the vowels or frequently used letters that could act as anchor points for a keyboard zone. A pre-typing training session that teaches users to associate characters with colours could be helpful in priming participants with the required cognitive association that may lead to better spatial knowledge with the introduction of a colour-coded keyboard. Additionally, expanding the study to include users with varying backgrounds could offer a more comprehensive understanding of the effectiveness of the visual aids. Moreover, future studies could compare different introduction points of the visual aid, to determine the most effective introduction timing for better supporting learning and enhancing users' spatial memory.

7 Conclusion

Our study examined the role of colour-coded visual aids in helping users learn two unfamiliar keyboard layouts. While quantitative results showed no significant performance gains directly related to the aids, qualitative feedback revealed that users appreciated the aids more when introduced after users' initial exposure to a new layout. This suggests that the timing of such aids is crucial, as early use may be overshadowed by initial cognitive overload, whereas delayed introduction of the visual aids could possibly play a key role in supporting users' learning. Even though visual aids did not directly boost users' performance, they may still promote learning by fostering engagement and reducing frustration. Future work should assess long-term spatial learning and explore different visual strategies, to better support users in transitioning to non-QWERTY layouts.

References

[1] Ahmed Sabbir Arif and Wolfgang Stuerzlinger. 2009. Analysis of text entry performance metrics. In *2009 IEEE Toronto International Conference Science and*

Technology for Humanity (TIC-STH) (2009-09). 100–105. doi:10.1109/TIC-STH.2009.5444533

[2] R. CONRAD, , and D. J. A. LONGMAN. 1965. Standard Typewriter Versus Chord Keyboard – an Experimental Comparison. 8, 1 (1965), 77–88. doi:10.1080/00140136508930777 Publisher: Taylor & Francis _eprint: https://doi.org/10.1080/00140136508930777.

[3] Mark Dunlop and John Levine. 2012. Multidimensional pareto optimization of touchscreen keyboards for speed, familiarity and improved spell checking. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2012-02-05) *(CHI '12)*. Association for Computing Machinery, 2669–2678. doi:10.1145/2207676.2208659

[4] Apostolos Gkoumas, Andreas Komninos, and John Garofalakis. 2016. Usability of Visibly Adaptive Smartphone keyboard layouts. In *Proceedings of the 20th Pan-Hellenic Conference on Informatics* (New York, NY, USA, 2016-08-10) *(PCI '16)*. Association for Computing Machinery, 1–6. doi:10.1145/3003733.3003743

[5] D. Gopher and D. Raij. 1988. Typing with a two-hand chord keyboard: will the QWERTY become obsolete? 18, 4 (1988), 601–609. doi:10.1109/21.17378

[6] Dominik Grüneis, Marc Kurz, and Erik Sonnleitner. 2023. Let Me Help You: Improving the Novice Experience of High-Performance Keyboard Layouts with Visual Clues. 13, 16 (2023), 9391. doi:10.3390/app13169391 Number: 16 Publisher: Multidisciplinary Digital Publishing Institute.

[7] Chun-Hsiung Huang. 2021. The Influence of Self-Efficacy, Perceived Usefulness, Perceived Ease of Use, and Cognitive Load on Students' Learning Motivation, Learning Attitude, and Learning Satisfaction in Blended Learning Methods. In *Proceedings of the 2020 3rd International Conference on Education Technology Management* (New York, NY, USA, 2021-02-17) *(ICETM '20)*. Association for Computing Machinery, 29–35. doi:10.1145/3446590.3446595

[8] Jussi P. P. Jokinen, Sayan Sarcar, Antti Oulasvirta, Chaklam Silpasuwanchai, Zhenxin Wang, and Xiangshi Ren. 2017. Modelling Learning of New Keyboard Layouts. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2017-02-02) *(CHI '17)*. Association for Computing Machinery, 4203–4215. doi:10.1145/3025453.3025580

[9] K. Lyons, D. Plaisted, and T. Starner. 2004. Expert chording text entry on the Twiddler one-handed keyboard. In *Eighth International Symposium on Wearable Computers*, Vol. 1. 94–101. doi:10.1109/ISWC.2004.19

[10] Kent Lyons, Thad Starner, and Brian Gane. 2006. Experimental Evaluations of the Twiddler One-Handed Chording Mobile Keyboard. *Human–Computer Interaction* 21, 4 (Nov. 2006), 343–392. doi:10.1207/s15327051hci2104_1

[11] Kent Lyons, Thad Starner, Daniel Plaisted, James Fusia, Amanda Lyons, Aaron Drew, and E. W. Looney. 2004. Twiddler typing: one-handed chording text entry for mobile phones. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York, NY, USA) *(CHI '04)*. Association for Computing Machinery, 671–678. doi:10.1145/985692.985777

[12] I. Scott MacKenzie and Shawn X. Zhang. 1999. The design and evaluation of a high-performance soft keyboard. In *Proceedings of the SIGCHI conference on Human Factors in Computing Systems* (New York, NY, USA, 1999-02-01) *(CHI '99)*. Association for Computing Machinery, 25–31. doi:10.1145/302979.302983

[13] Laurent Magnien, Jean Leon Bouraoui, and Nadine Vigouroux. 2004. Mobile devices: soft keyboard text-entry enhanced by Visual Cues. In *Proceedings of the 1st French-speaking conference on Mobility and ubiquity computing* (New York, NY, USA, 2004-03-01) *(UbiMob '04)*. Association for Computing Machinery, 158–165. doi:10.1145/1050873.1050908

[14] Aunnoy K Mutasim, Anil Ufuk Batmaz, Moaaz Hudhud Mughrabi, and Wolfgang Stuerzlinger. 2023. Does Repeatedly Typing the Same Phrase Provide a Good Estimate of Expert Text Entry Performance?. In *Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2023-12-19) *(CHI EA '23)*. Association for Computing Machinery, 1–8. doi:10.1145/3544549.3585647

[15] R. William Soukoreff and I. Scott MacKenzie. 2003. Metrics for text entry research: an evaluation of MSD and KSPC, and a new unified error metric. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2003-12-05) *(CHI '03)*. Association for Computing Machinery, 113–120. doi:10.1145/642611.642632

[16] Keith Vertanen and Per Ola Kristensson. 2011. A versatile dataset for text entry evaluations based on genuine mobile emails. In *Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services* (New York, NY, USA, 2011-05-30) *(MobileHCI '11)*. Association for Computing Machinery, 295–298. doi:10.1145/2037373.2037418

[17] Jacob Wobbrock. 2007. Measures of Text Entry Performance. In *Text Entry Systems*. 47–74. doi:10.1016/B978-012373591-1/50003-6 Journal Abbreviation: Text Entry Systems.

[18] Shumin Zhai, Hunter , Michael, , and Barton A. Smith. 2002. Performance Optimization of Virtual Keyboards. 17, 2 (2002), 229–269. doi:10.1080/07370024.2002.9667315 Publisher: Taylor & Francis _eprint: https://www.tandfonline.com/doi/pdf/10.1080/07370024.2002.9667315.