Multi-level Keypresses with Hall Effect Keyboards

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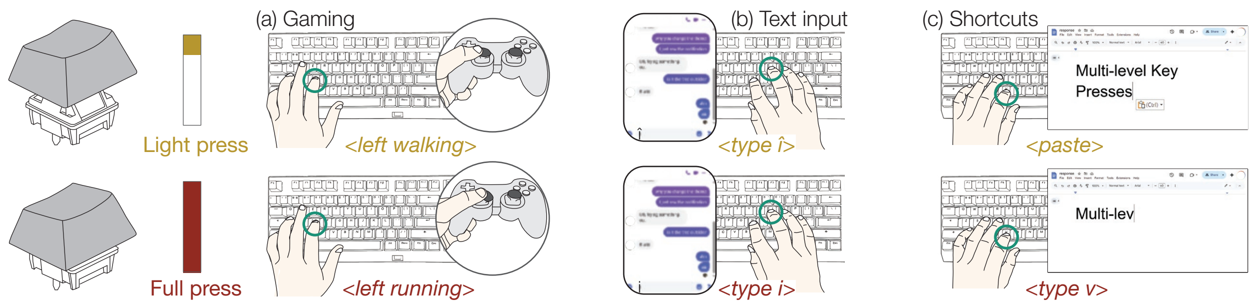

Figure 1: Potential applications using multi-level keypresses: (a) For gaming, light-press “D” to walk left, and full-press to run left; (b) For text input, light-press “I” to type circumflex î, and full-press to type regular i; (c) For shortcuts, light-press “V” to paste, and full-press to type v.

ABSTRACT

Hall effect keyboards use magnetic fields to detect the degree of pressing for each key, enabling continuous and precise sensing of traversal distance compared to a single key switch. If users can control the depth of their key presses, many new interaction opportunities become possible. We explored this richer interaction space of the Hall effect keyboard with a controlled experiment that examined user ability to perform multiple levels of pressing distance with different fingers. Results showed that most participants can accurately press keys with two levels, with the index fingers preferred for multi-level keypresses. We demonstrate the interaction potential of Hall effect keyboards by identifying user abilities and strategies, summarizing design considerations, and discussing practical applications.

CCS CONCEPTS

• **Human-centered computing** → **Interaction techniques**.

KEYWORDS

Interaction techniques, keyboards, controlled experiments

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1 INTRODUCTION

Keyboards are a primary input device for desktop and laptop interaction. However, due to the limited number of keys, and the fact that keys can only be in two states, users must rely on shortcuts with modifier keys [23], or must switch to mouse input for mode switching, menu selection, or issuing frequent commands. To enable more expressive interactions with physical keyboards, researchers have explored the integration of various sensors, including pressure sensors [10], capacitive sensors [24, 25, 28], and cameras [33]; these have been used to detect keyboard gestures such as strokes [29, 32], multi-modal shortcuts [5, 34], and near-keyboard hand postures [6].

A new type of keyboard has recently been introduced that provides the ability to sense the amount of travel in each key – these *Hall effect* keyboards [30] replace each key’s metal contact switch with a magnetic sensor that detects the amount of the key’s travel. With this continuous magnetic value, keyboards can support multi-level controls based on the traversal distance of the key, thus expanding the keyboard’s input vocabulary. However, there is little information available to guide the design of new interaction techniques that use Hall effect sensors. The closest related research has considered multi-level input by detecting the pressing force of a key. Dietz et al. designed a pressure-sensing keyboard and demonstrated applications such as nuanced control in games, adjusting font size based on pressure force, and enhanced typing functions [10]. With the same pressure-based hardware, Jong et al. enabled two-level controls within a key press event, and studied the learnability of these interaction methods [9]. However, no previous work has studied the user’s ability to express multi-level keypress interactions. Motivated by the potential for developing new interaction techniques with Hall effect keyboards, we ran an experiment to answer the research question of how well people can perform multi-level keypresses with different fingers.

We conducted an in-person controlled study to investigate users' ability to press keys with various depth levels, using different fingers. The study asked participants to press keys to a specified press distance, across two, three, and four levels of key travel (e.g., the three-level test involved *light*, *medium*, and *full* key travel). We included trials for each of the eight 'home row' fingers that are situated on the *A*, *S*, *D*, *F*, *J*, *K*, *L*, and *Semicolon* keys. We recorded the accuracy of each keypress, the time needed to complete the trial, and subjective responses about the learnability and effort of each type of press. The study results showed that two-level pressing was accurate (92.4%), even with very little practice, and was consistently preferred by participants over three-level or four-level setups. The accuracy of three-level pressing was lower (75.1%), but participants still rated it as being easy to learn, with neutral mental demand. Four-level pressing had the lowest accuracy (61.6%) with the highest effort needed.

Overall, our study shows that two-level pressing can be a viable augmentation to keyboard interactions, and the extra level of input could be beneficial in a wide variety of contexts, from more expressive keyboard shortcuts to additional control for expert typists. Our work contributes the first evaluation of user ability with multi-level pressing based on traversal distance in a Hall effect keyboard.

2 RELATED WORK

Our work builds on research into keyboard interactions, keyboard gestures, and multi-level pressing within a key.

2.1 Keyboard Gestures

To expand the interaction space of a keyboard, pressing keys in sequence or pressing multiple keys simultaneously allows for additional expressiveness without requiring extra sensors or modifications. Many sequence-based commands are in use, such as activating shortcuts with a modifier key (e.g., Ctrl-C for copy). Other techniques have also been proposed by researchers. Wobbrock et al. proposed a 4-key gestural text input system in which pressing keys in sequence produces the Roman letter that matches the shape [29]. Users can perform such gestures eyes-free with high learnability and speed. Inspired by gesture typing on a touch screen, Zhang and Li examined the characteristics of drawing stroke gestures on an ordinary keyboard [32]. They proposed a recognizer to distinguish regular and gesture typing with high accuracy, and demonstrated simultaneous input of text entry and gesture shortcuts. Au et al. studied chording techniques by pressing or releasing keys at the same time, which achieved competitive performance compared to modifier-based shortcuts [2].

Previous work also explored the input space around keyboards [6, 16, 31] and typing postures [5, 33, 34]. Chhibber et al. proposed a hand posture system around the keyboard with dimensions of hand position, openness, and wrist rotation [6]. By identifying which finger, hand, and hand posture is used to press a key, multiple commands can be mapped to the same key [34]. A similar idea was proposed by Buschek et al. by detecting arm and wrist rotation while pressing a key to extend keyboard shortcuts [5].

To further increase the input vocabulary of a keyboard, various sensors have been integrated into keyboard hardware to detect touch gestures [12, 15, 17, 18, 24–26, 28] and to provide visual cues [3]. Taylor et al. augmented a keyboard with IR sensors to detect gestures on and above the keyboard, such as on-key swipes, shapes, hovers, and multi-touch gestures [26]. Shi et al. transformed each keycap into a touchpad with capacitive sensing, and evaluated touch interactions on individual keys, such as swipes or drawn shapes [25].

In this paper, we also studied keyboard interaction with a consumer keyboard that has no extra sensors or modifications other than the Hall-effect switches; in contrast to previous work, we focus on enabling modes within a key by sensing the traversal distance of a press event.

2.2 Multi-level pressing

With pressure sensing, it is possible to distinguish different pressing forces within a key on a physical keyboard [9, 10, 19] or a soft keyboard [1, 4, 11, 14]. Dietz et al. designed a pressure-sensitive keyboard by sensing the resistance of the contact switch [10]. When a key is pressed down with more force, the key dome is squeezed down and the resistance is decreased due to the growing contact region. With this sensing technique, they enabled continuous control for gaming, changing text size, and modal typing. Jong et al. further proposed 2-level control within one press with the same hardware [9]. After a soft key-press and key-hold, a relevant hard or medium press can be applied to activate shortcuts, replacing modifier key combinations. Brewster and Hughes detected light and hard taps on a touchscreen keyboard to type lowercase and uppercase letters [4]. With a similar pressure sensing method, keyboard layouts can be reduced to a telephone keypad layout [19] or a split-keyboard layout to solve the 'fat thumb' problem on size-limited soft keyboards [14].

The traversal distance of a key is one dimension of a key press, which is correlated to but different than the force hitting a key. McPherson and Kim defined this difference for the piano keyboard: the weight dimension is the force hitting the key bed, and the depth dimension is the traversal distance of a key [20]. Full presses (i.e., where the key reaches the key bed) and partial presses are defined in the depth dimension. We explored interactions within the depth dimension that can be supported with a Hall effect keyboard.

Dietz et al. [10] also utilized the traversal distance of a key for a pressure-sensitive keyboard. However, the pressure was sensed only after the key was clicked (i.e., the switch was contacted), and the mapping between distance and pressure value is unclear. Moreover, user capability for performing multi-level depth pressing has never been formally investigated. Our work contributes the first investigation of user ability in pressing keys with multiple distance levels, from zero to fully pressed, with a Hall effect keyboard.

3 EXPERIMENT

The goal of this experiment is to formally investigate the user's ability to consistently perform multi-level pressing with different fingers. We examined the accuracy and speed of each pressing level, as well as participant preference and strategy. The study was approved by the ethics board of the University of Saskatchewan.

3.1 Participants

We recruited 24 participants for the in-person study (11 identified as men and 13 as women; 3 reported they were left-handed). Participants were recruited using a university announcement system and by word-of-mouth, and received a $15 remuneration. Participants were required to have full use of both hands and fingers to be able to type on the keyboard. The demographics of the participant age ranges, daily physical keyboard use, and history of mechanical keyboard use are summarized in Table 1. Two people reported minor experience using a Hall effect keyboard (both less than one year).

3.2 Apparatus

The study used a Wooting Two HE [30] full-size Hall effect keyboard (Figure 2a). Each key includes an analog magnetic switch, with an approximate linear force distribution from 34 to 52 cN, traversing from 0 to 4 mm. We split the traversal distance into four pressing segments (Figure 2b):

- S1: the distance is within the range [0.2, 1.4) mm.
- S2: the distance is within the range [1.4, 2.8) mm.
- S3: the distance is within the range [2.8, 3.92) mm.
- S4: the distance is greater than or equal to 3.92 mm.

A key is registered as pressed when the travel distance exceeds 0.2 mm. We then used the maximum traversal distance during a press event to determine the pressing level. Based on our initial explorations and pilot studies, the unbalanced segments stated above were designed and deployed for two reasons. First, users were expected to fully press a key for a full level, so we limited the fourth segment to be as small as possible. Second, we enlarged the first two segments due to the likelihood of overshooting a lighter press.

The experiment was deployed as a web application, using the wooting-js [7] library to read the raw data from the analog keyboard (Figure 2c). During the experiment, no visual feedback for the real-time traversal distance was provided. However, after each task trial, participants received about whether the trial was correct or not, and the reason for an incorrect attempt.

3.3 Procedure

The experiment had three sections: (1) instructions and practice session; (2) main session with measured trials; and (3) post-experiment questionnaire. We first greeted participants and obtained informed consent, and provided a brief instruction session, including the experiment goal and flow, the web-based interface, and the details of the Hall effect keyboard. During this section, participants spent 5 to 10 minutes typing with the Hall effect keyboard using a practice interface with real-time feedback about press distance, as well as the recognized pressing level. Participants were asked to try out every level with selected keys to develop a sense for multi-level pressing. In this experiment, we chose the 8 keys of the 'home row' with natural finger placements, and requested that participants press the target key without changing fingers (e.g., they were asked to press "A" with the left pinky, and "J" with the right index finger). The goal of this setup was to understand pressing performance across corresponding fingers.

Table 1: Experiment demographics (24 participants in total).

Age		Daily keyboard use (hours)		Mechanical keyboard use (years)	
18-24	17	More than 8	5	None	10
25-34	4	4-8	8	Yes, less than 5	8
35-44	3	2-4	9	Yes, 5-10	2
		1-2	2	Yes, more than 10	4

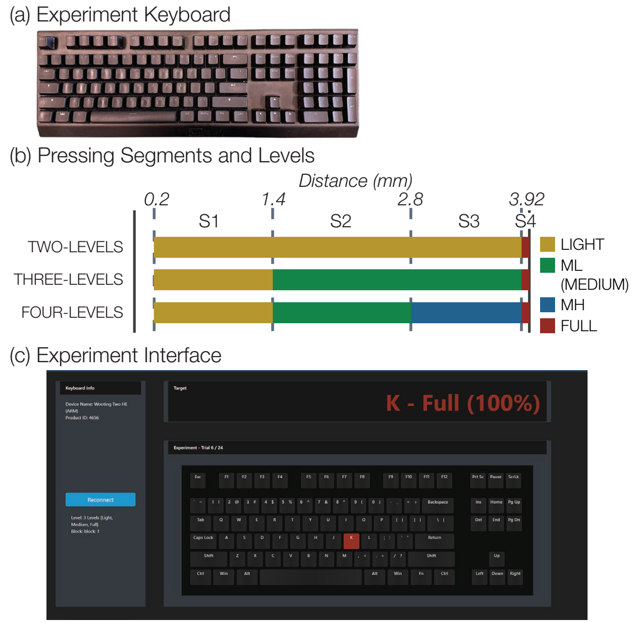

Figure 2: Experiment setup: (a) the Wooting Two HE keyboard; (b) the segments of traversal distance and mapping to corresponding LEVEL; and (c) the experiment interface.

After participants felt comfortable with the pressing method, they completed the main study in three sessions, each with a different level count (described in section 3.4). Each session included 5 blocks of key-pressing tasks, followed by a questionnaire for that session. At the end of the study, participants completed a questionnaire about their overall experience. The study took approximately 50 minutes in total. The full text of the questions is provided in the supplementary files[1].

3.4 Design

The study used a within-participants design with one primary independent variable: LEVEL-COUNTS with 3 groups (TWO-LEVELS, THREE-LEVELS, FOUR-LEVELS). BLOCK, pressing LEVEL, and target KEY form secondary independent variables.

- For TWO-LEVELS, there were 2 LEVEL (LIGHT, FULL).
- For THREE-LEVELS, there were 3 LEVEL (LIGHT, MEDIUM, FULL).
- For FOUR-LEVELS, there were 4 LEVEL (LIGHT, MEDIUMLOW, MEDIUMHIGH, FULL).

The mappings between LEVEL and pressing segments are shown in Fig. 2b. There were 8 KEY (A, S, D, F, J, K, L, SEMICOLON) and 5 BLOCK per LEVEL-COUNTS. Each BLOCK includes every combination

[1] See supplementary materials for full study questionnaire

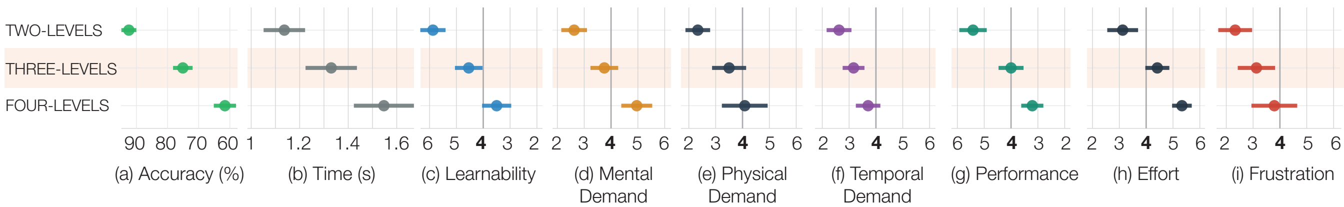

Figure 3: Comparison of level-counts: (a) Accuracy; (b) Time; (c) Learnability rating; (d) Mental demand rating; (e) Physical demand rating; (f) Temporal demand rating; (g) Performance rating; (h) Effort rating; and (i) Frustration rating. Note: accuracy, learnability rating, and performance rating are inverted to enable comparison with time and other subjective ratings (left-most points in each sub-graph are better). Error bars are 95% confidence intervals.

of level and key once. The order for level-counts was counterbalanced using a Latin square, and the combination of level and key within a block was randomized.

The primary measures computed from logs are *Accuracy* and *Time*. *Accuracy* is the proportion of trials that are correct. *Time* is the elapsed time from the previous target keypress until the current target keypress. In addition, the questionnaire provided 7 subjective measures per level-counts (*Learnability*, *Mental Demand*, *Physical Demand*, *Temporal Demand*, *Performance*, *Effort*, and *Frustration*). Within each level-counts, there is one extra subjective measure (*Ease*) per level and per key. All subjective ratings are numeric from 1 to 7.

In summary: 3 level-counts (with 9 total level) × 8 key × 5 block = 360 data points per participant.

3.5 Results

We used the $1.5 \cdot$IQR (interquartile range) rule to detect trial outliers for each combination of participant and level-counts according to *Time*. In total, 437 trials (5.1%) were removed. For each measure, trials were aggregated by participant and factors being analysed.

Because residuals for *Time* were not normally distributed, Tukey's Ladder of Powers transformation [27] was used for statistical analysis. We visually inspected the Q-Q plot to confirm normality. When the assumption of sphericity was violated, degrees of freedom were corrected using Greenhouse-Geisser ($\epsilon < 0.75$). The residuals for all subjective measures were also not normally distributed, so Friedman tests with Holm correction and Wilcoxon signed-rank post-hoc tests were used.

We first performed the analysis on the primary independent variable. Figure 3 summarizes the main results for level-counts. We used one-way repeated measures ANOVA for *Accuracy* and *Time*, and pairwise t-test with Holm's correction for post-hoc tests. We then perform level × key analysis for each level-count. The main results are shown in Figure 4. Generalized linear mixed models were applied for *Accuracy* because the distribution is close to a Poisson distribution. For *Time*, we used a factorial repeated measures ANOVA with Holm-corrected pairwise comparisons.

3.5.1 Learning Effect. Due to the potential of participants improving during the experiment, we examined whether earlier blocks were more error-prone and should be removed. A block × level-counts test was used. We found a main effect of block on *Accuracy* ($F_{4,92} = 3.38$, $p < .05$, $\eta^2_G = .019$), but no interaction effects involving block. Pairwise t-tests showed that block 1 was significantly less accurate than block 4 ($p < .05$); therefore, we removed block 1 in the subsequent analysis due to the learning effect.

3.5.2 Level Counts. Overall, two-levels is the most accurate, fastest, and most preferred in terms of all subjective ratings (Figure 3, see A.1: Table A.1 for main effect tests).

In terms of statistical differences, for *Accuracy*, two-levels (92.4%) is the most accurate, followed by three-levels (75.1%), and four-levels (61.6%) is the least accurate. For *Time*, two-levels (1.14s) is the fastest, followed by three-levels (1.33s), and four-levels (1.55s) is the slowest. For *Learnability*, participants were asked to rate how easy it was to learn how to type in each level count condition. two-levels (5.9) is the easiest, followed by three-levels (4.5), and four-levels (3.5) is the hardest.

We used NASA-TLX questions for other subjective ratings. two-levels (2.6) is the least mentally demanding, followed by three-levels (3.8), and four-levels (5.0) is the highest. two-levels (2.3) is the least physically demanding, followed by three-levels (3.5), and four-levels (4.1) is the highest. two-levels (2.6) is the least temporally demanding, followed by three-levels (3.2), and four-levels (3.7) is the highest. Participants believed that they performed best in two-levels (5.4), followed by three-levels (4), and four-levels (3.2). Lowest effort is needed for two-levels (3.1), followed by three-levels (4.4), and four-levels (5.3) is the highest. Participants feel less frustrated with two-levels (2.3) than three-levels (3.1), and four-levels (3.8).

3.5.3 Two levels. In general, participants performed both full and light press accurately (higher than 90%), and rated a full press or pressing with index fingers on both hands (f and j keys) easier. The main results for two-levels are shown in green lines in Figure 4.

For level, a full press (6.92) is rated easier to perform than a light press (5.12) (A.2: Table A.3a). For key, pressing a is the fastest (1.0 seconds). We also found pressing s (1.09s), f (1.14s), and semicolon (1.11s) were faster than pressing k (1.26s), and l (1.21s); and pressing d (1.16s) is faster than k (A.2: Table A.2). Pressing f (6.38) and j (6.54) are rated as easy compared to the other keys (A.2: Table A.3b).

3.5.4 Three levels. Overall, a full press was fast with high accuracy, and was also rated the easiest. Similar to the results from two levels, pressing keys with index fingers (f and j) on both hands are rated easier. The main results for three-levels are shown with orange lines in Figure 4.

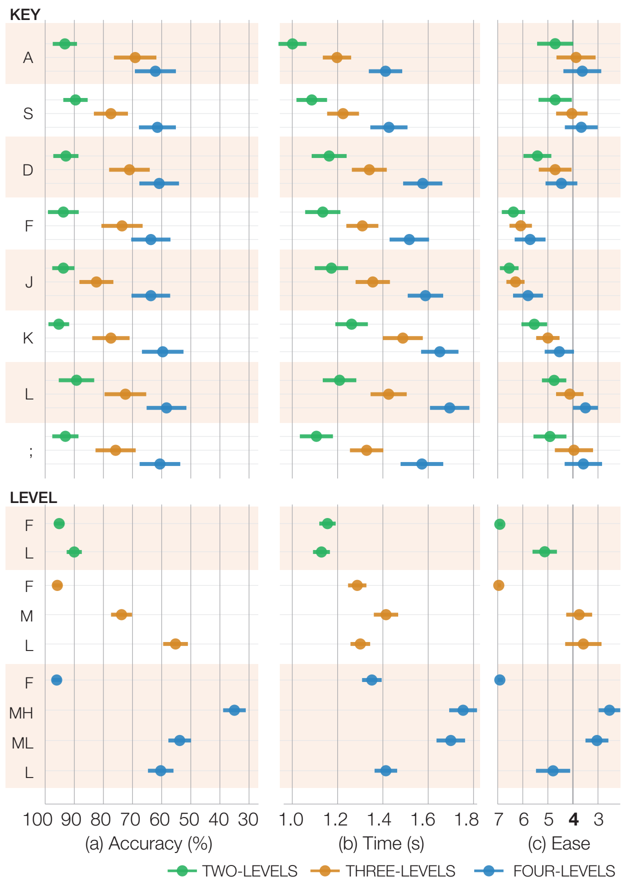

Figure 4: Comparison of KEY and LEVEL within TWO-LEVELS, THREE-LEVELS, and FOUR-LEVELS: (a) Accuracy; (b) Time; (c) Ease rating. Note: accuracy and ease rating are inverted to enable comparison with time (left-most points in each subgraph are better). Error bars are 95% confidence intervals.

We found a main effect of LEVEL. FULL is the most accurate level (95.8%), following by MEDIUM (73.7%), and the LIGHT is the least accurate (55.2%) (A.3: Table A.4). Both FULL (1.29s) and LIGHT (1.3s) are faster than MEDIUM (1.41s) (A.3: Table A.5a). Participants rated FULL (6.96) easier than MEDIUM (3.75) and LIGHT (3.58) (A.3: Table A.6a).

There was a main effect of KEY. Pressing A (1.20s) and S (1.23s) are the fastest; pressing D (1.34s), F (1.31s), and SEMICOLON (1.33s) are faster than K (1.49s) and L (1.43s); and pressing J (1.36s) is also faster than K (A.3: Table A.5b). It is easier to press F (6.08) and J (6.29) than all other keys, and K (5) is also slightly easier than L (4.12) (A.3: Table A.6b).

We found interactions between LEVEL and KEY for *Time*. We report the difference between KEY within the same level: within FULL, pressing A is faster than D, K, and L; within MEDIUM, pressing S is faster than F, J, K, and L; and within LIGHT, pressing A is faster than K and L (A.3: Table A.5c).

3.5.5 Four levels. In general, a full press outperformed all other levels; the performance with non-full presses was lower due to confusion between levels. The main results for FOUR-LEVELS are shown in blue lines in Figure 4.

A main effect was found for LEVEL. For *Accuracy*, FULL (96.1%) is the highest, and MEDIUMHIGH (35%) is the lowest (A.4: Table A.7). For *Time*, all pairs are significantly different, with the order FULL (1.35s), LIGHT (1.41s), MEDIUMLOW (1.7s), and MEDIUMHIGH (1.75s) (A.4: Table A.8a). For *Ease*, FULL (6.92) is rated the easiest, and LIGHT (4.79) is rated the second (A.4: Table A.9a).

We found a main effect of KEY. For *Time*, pressing A (1.41s) and S (1.43s) are the fastest; pressing F (1.52s) is faster than J (1.59s), K (1.65s), and L (1.7s); and pressing D (1.58s) and SEMICOLON (1.57s) are faster than L (A.4: Table A.8b). For *Ease*, pressing F (5.71) and J (5.79) are rated the easiest (A.4: Table A.9b).

We also found interactions between LEVEL and KEY for *Time*. For FULL, pressing A is faster than D, K, and L; and pressing S and F are faster than K and L. For LIGHT, pressing A and S are faster than K and L; and pressing F and SEMICOLON are faster than L (A.4: Table A.8c).

4 DISCUSSION

We summarize design recommendations based on experiment results, and discuss study limitations and potential applications.

Levels and Strategies. The study clearly showed that users can press keys at two levels (a light and a full press) quickly and with high accuracy. This result supports the interaction designs proposed in previous work [9, 20]. In our study, all participants were confident that they can correctly perform two-level pressing, and 11 people were confident that they can perform three-level pressing; however, none of the participants were confident about four-level pressing.

Pressing a key with more than two levels was slower, which is likely related to its higher mental load: *"For the more complicated levels, I had to think more"* [P18]; and *"For medium low level, I put more effort into thinking as to how far I was pushing it down"* [P6]. However, participants' strategies for medium-level pressing may have also contributed to the longer completion times: *"I found it easier to type slower for levels that were medium or in between low and high"* [P19]; and *"For medium levels, I tried to press it a little slower to be more accurate"* [P16].

Full-press actions had the highest accuracy and were rated as easiest across all conditions. Participants mentioned that their regular pressing behaviour is similar to a full press: *"I liked using the full level the most, because I am used to press a key down fully when regularly typing"* [P16]. Unsurprisingly, 16 participants reported their strategy for a full press is bottoming out the key and pressing with substantial force.

Light-press actions also had high accuracy in the two-level condition (89.7%) due to the higher range of traversal distance, but there were still 10.3% errors (Fig. 5a). Participants mentioned that they would sometimes accidentally press all the way down: *"Even though in my brain I knew that I had to press half way down, sometimes my finger would still press all the way down"* [P18].

Participants found it is hard to press a key only a short distance: the average pressing distance for light-press actions was 1.89mm (SD = 0.68) for two levels, 1.43mm (SD = 0.34) for three levels, and 1.39mm (SD = 0.37) for four levels. The latter two are closer to the default threshold of a light press (Figure 5b, c). Overall, participants gave divergent feedback about light presses: *"The light one*

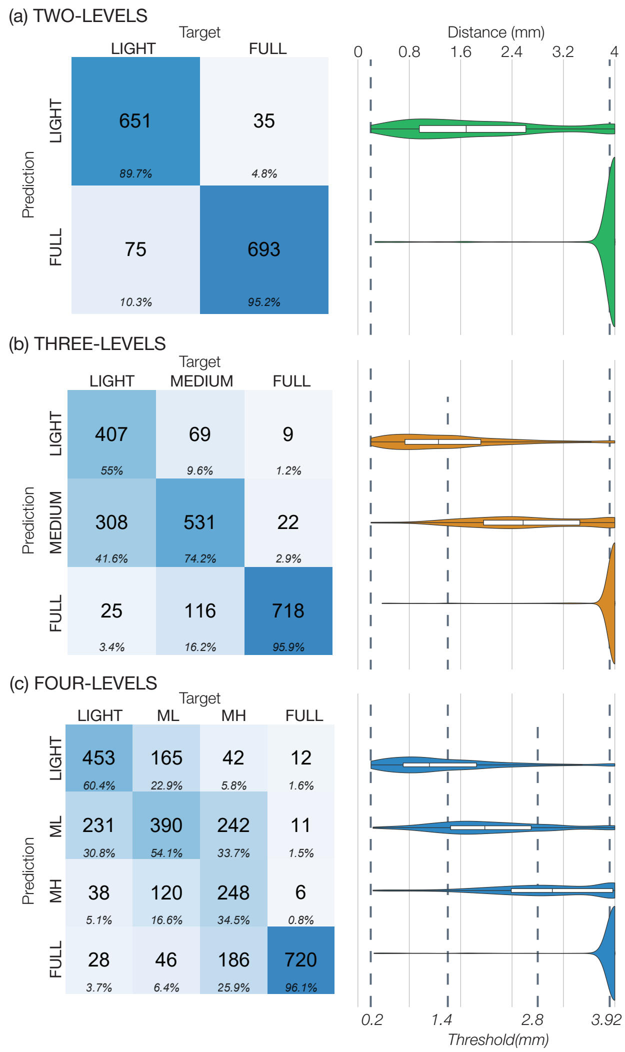

Figure 5: Confusion matrix and user pressing distance for each LEVEL-COUNTS. The violin plot and the box plot show the distribution of actual pressing distance for each LEVEL.

was tricky at times because I felt like I could ever so barely push it, and anything more would end up in the medium range" [P6]; and *"light (press) was easy because I just knew I had to barely press the key"* [P17]. Moreover, even though participants were confident using the light level, performing a light press might reduce physical comfort: *"(Other than a full press) The only other level I felt somewhat confident using was the light level, but using the light level felt shaky when there were more than 2 levels to type at"* [P24]. Some participants used particular strategies for light pressing, including tapping(6), flicking (2), or pressing on a specific location of a key (2): *"For light levels, I would do more of a sliding action than pressing down on the key"* [P1]; and *"(for light), try to type at the edge of the keyboard (key)"* [P13].

In the four-level condition, participants reported difficulties in differentiating between the two medium levels, which is also revealed in the confusion matrix shown in Figure 5c: *"Medium-low and medium-high were harder because I could not really get used to how hard I had to push the key to reach either of them"* [P17]; and *"It was very difficult to calibrate my strength when hitting medium-high versus medium-low"* [P14]. Furthermore, both of the medium levels were easy to confuse with a light or a full press: *"Medium-low was the hardest to do as it felt like I would press it and end up being in the light section or press too hard and end up higher"* [P6]; and *"It was more difficult to judge when to let go of the key for the medium-high level without fully pressing the key down"* [P5].

In general, the observed distribution of pressing distances per level follows the rules we used for distance segments (Figure 5): for example, the mean distances of light presses were deeper, and the IQR for the medium-low level was within the second segment range. However, segment thresholds will vary for each user, especially for experts. We show the distribution of pressing distance for each level of each participant in the Appendix (A.5: Figure A.1). We observed that when participants performed well with the three-level or four-level conditions, they were able to make a consistent light press, which created a wider range for the medium levels. We plan to carry out further investigations into customized thresholds.

Overall, our main recommendation is to support two-level key presses, due to our participants' strong performance and preference. This confirmed the interaction designs within a single key described in previous work [4, 9, 14, 20]. To increase the expressiveness of a standard keyboard, it is possible to integrate a dual-action switch inside each key to enable two-level pressing. In addition, although pressing a key in three levels was less accurate in the study, this configuration also has potential – particularly if users are given additional practice, and if a customized threshold is used.

Comparison with Force-based Inputs. Previous work has investigated the performance of multi-level force input on rigid [8, 22] or soft surfaces [13] for visual targeting tasks. BackXPress studied finger tapping force, ranging from 1 to 6 N, on the back of a mobile device [8]. Their results showed 86.8%, 75.1%, and 69.4% accuracy for 3, 5, and 7 force levels. More recently, Fruchard et al. revealed high force input accuracy (94.7%) for 20 levels with wider force span (0 - 5.5 N) and quick release selection technique [13].

The traversal distance of a keypress is correlated to the pressing force. However, our results showed lower accuracy after 3 levels, which is different from previous work. There are two possible reasons. First, the force range of the Hall effect keyboard is less than 40 cN, which is significantly smaller than other force-based mechanisms. Second, unlike the visual targeting tasks used in earlier studies, we did not provide visual feedback during the task. Ramos et al. revealed lower performance in the partial visual feedback condition (i.e., no real-time force feedback, but the target will change colour when the force is inside the target range.) compared to the full visual feedback condition [22]. Accuracy is likely to further decrease when participants can only rely on their memory and cognition.

To support more levels with the Hall effect keyboard, the force resistance profile of the key switch could be modified to enlarge the force span within the fixed traversal distance. However, this might also increase the difficulty of pressing a key for regular typing. Further investigation is needed for this trade-off.

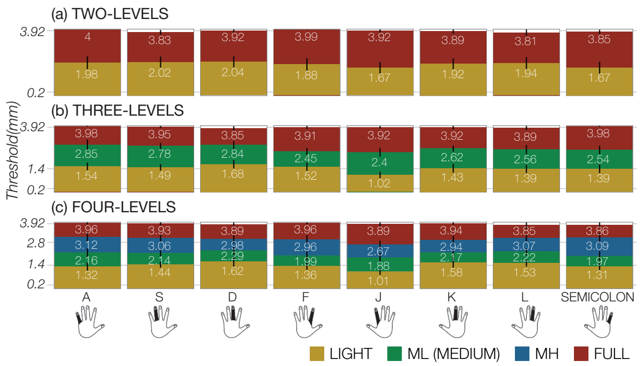

Figure 6: The mean of pressing distance defined by LEVEL and KEY of (a) TWO-LEVELS, (b) THREE-LEVELS, and (c) FOUR-LEVELS. (error bars are 95% confidence intervals)

Keys and Fingers. Faleel et al. found that different typing forces were applied to different keys on a virtual keyboard, based on the finger that was used [11]. To explore this issue with our keyboard, we mapped each key to a specific finger and analyzed performance between fingers.

First, there was no main effect of key in terms of accuracy. Second, we compared the actual pressing distance for each level and key, and again did not find significant differences between keys, in any condition (Figure 6).

Surprisingly, in most cases, pressing "A" (left pinky finger) and "S" (left ring finger) were fast, and "K" (right middle finger) and "L" (right ring finger) are slower. The familiarity of pressing those keys may be one reason for the difference, since in English, "A" and "S" have higher frequency (8.04% and 6.51%) [21]. After seeing the target key on the screen, participants may have therefore had quicker reaction for these two keys. In the experiment interface, we also provided the keyboard layout with the task visualization (Figure 2c). However, we still observed that participants would sometimes press the wrong key, especially for "K" and "L". The frequent use of the left pinky finger for pressing the modifier key (e.g., Ctrl or Shift) may be another reason for the increase in speed of the "A" key: *"I think I was more proficient with my pinky finger than I was with my ring or middle finger because I'm used to holding down the shift key with it to type capitals, so I'm already used to applying pressure to it for extended periods of time"* [P20].

In terms of subjective difficulty, the two index fingers were rated as the easiest for controlling the pressing distance. The dexterity and the regular usage of the index fingers are two main reasons for this result: *"Our index fingers and middle fingers are usually our stronger fingers"* [P15]; and *"I preferred my index and middle fingers, because I regularly type with them."* [P16]. Even though no accuracy difference was found between fingers, we can find slightly better finger controllability for right index finger ("J") (figure 6b, c). The average pressing distance for light and medium levels with the index fingers was smaller than for the other fingers, suggesting that users can move their index fingers with finer granularity. As a result, 22 participants preferred using their two index fingers for multi-level pressing.

In our experiment, participants did not need to move their fingers to reach the keys, which is different from real typing scenarios. Performance for multi-level typing might decrease due to finger movement in the horizontal plane; future work will expand on our experiment to investigate multi-level typing performance with additional finger movement.

Limitations. We found a weak learning effect from the block analysis, suggesting that accuracy will increase after longer usage. Before the experiment, participants completed a practice session of 5 to 10 minutes – but this is still a very small amount of practice for what was a completely novel technique for participants. Three participants mentioned their music background as a potential factor leading to better performance: *"I believe my experience as a musician (guitar and piano) affected my finger dexterity, which played into how well I was able to control the analog keys"* [P6]; and *"Because of my background playing acoustic finger-style guitar for decades, I think I would have picked up 4 levels easier then typical users"* [P22]. A longitudinal experiment with sufficient practice is planned in order to study longer-term learning effects.

Our goal in the study was to test how well can people reliably perform multi-level key presses, so we did not provide real-time visual feedback for the pressing distance, and only showed the results after each trial. During the experiment, we observed that some participants had multiple errors in a row, indicating that feedback from the previous trial might have had a side effect on behaviour for the following trial. One participant mentioned that he might have over-adjusted his pressing distance after an incorrect trial: *"If I pressed the wrong key (level), I would press the next key (trial) really hard to be "confidently right""* [P21]. A study with different forms of trial feedback, or longer breaks between each trial, might reduce these effects.

We focused on the pressing levels within a single key, and only evaluated a limited number of keys in the study. Future work can expand this interaction space with multi-key gestures, including pressing keys at different levels simultaneously or sequentially.

Applications. Participants suggested potential practical applications of the multi-level keys in four areas: gaming, text input, shortcuts, and physical ability training features.

For gaming, similar to ideas proposed by Dietz et al. [10], pressing different levels could indicate actions that have a continuous scale, such as walking speed or attacking power, as well as discrete functions, such as emulating different controls (Figure 1a).

For text input, individual keys could be mapped to multiple characters (e.g., accents, numbers, or symbols) or styles (e.g., bold, uppercase, or subscript), and pressing at a different level could directly insert those characters without extra steps: *"it could be used for accents, especially in working with different languages that using letters that aren't generally on the "normal" english keyboard"* [P18] (Figure 1b).

Multi-level key presses could also be used to replace system shortcuts, such as nested menus and hotkeys: *"It could replace modal editors like vim, where instead of having to toggle between insert or normal mode, you could just have the two levels of the key be the way to denote which mode the command is in"* [P22] (Figure 1c).

Finally, training or monitoring applications could integrate the pressing levels as input data: *"Monitoring stress level with the help* *of typing behaviour on how deep I press the keys"* [P7]; and *"(It can be) used to improve (finger) dexterity, especially with neurological deficits (i.e. from a rehabilitation perspective)"* [P9].

5 CONCLUSION

We conducted a controlled experiment to investigate user ability to press keys with multiple levels of travel distance with a Hall effect keyboard. We found that all users can perform two-level pressing with high accuracy and speed, and that two-level pressing was preferred and rated as least difficult. Three-level key presses are more difficult and less accurate, but most subjective ratings are greater than neutral. The distribution of pressing distance for each participant shows the potential for additional levels if configurable thresholds can be applied, and if additional practice is given. With two-level key presses, we can double the interaction space of a keyboard, and further enable rich shortcuts or additional typing controls. Our investigation shows the potential of Hall effect keyboards for harnessing the user's multi-level pressing abilities. Our work encourages interaction designers to further increase the input vocabulary available with keyboards (e.g., enabling multi-key gestures, or joystick features with analog values), and to create novel gesture types (e.g., multi-finger pressing with one finger serving as an anchor) with Hall effect keyboards.

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REFERENCES

[1] Ahmed Sabbir Arif and Wolfgang Stuerzlinger. 2013. Pseudo-pressure detection and its use in predictive text entry on touchscreens. In *Proceedings of the 25th Australian Computer-Human Interaction Conference: Augmentation, Application, Innovation, Collaboration* (Adelaide, Australia) *(OzCHI '13)*. Association for Computing Machinery, New York, NY, USA, 383–392. https://doi.org/10.1145/2541016.2541024

[2] Oscar Kin-Chung Au, Kira Yip-Wo Yeung, and Jacky Kit Cheung. 2016. DownChord and UpChord: A New Style of Keyboard Shortcuts based on Simultaneous Key-down and Key-up Events. In *Proceedings of the Fourth International Symposium of Chinese CHI* (San Jose, USA) *(Chinese CHI '16)*. Association for Computing Machinery, New York, NY, USA, Article 3, 10 pages. https://doi.org/10.1145/2948708.2948715

[3] Florian Block, Hans Gellersen, and Nicolas Villar. 2010. Touch-display keyboards: transforming keyboards into interactive surfaces. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Atlanta, Georgia, USA) *(CHI '10)*. Association for Computing Machinery, New York, NY, USA, 1145–1154. https://doi.org/10.1145/1753326.1753498

[4] Stephen A. Brewster and Michael Hughes. 2009. Pressure-based text entry for mobile devices. In *Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services* (Bonn, Germany) *(MobileHCI '09)*. Association for Computing Machinery, New York, NY, USA, Article 9, 4 pages. https://doi.org/10.1145/1613858.1613870

[5] Daniel Buschek, Bianka Roppelt, and Florian Alt. 2018. Extending Keyboard Shortcuts with Arm and Wrist Rotation Gestures. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3173574.3173595

[6] Nalin Chhibber, Hemant Bhaskar Surale, Fabrice Matulic, and Daniel Vogel. 2021. Typealike: Near-Keyboard Hand Postures for Expanded Laptop Interaction. *Proc. ACM Hum.-Comput. Interact.* 5, ISS, Article 486 (Nov. 2021), 20 pages. https://doi.org/10.1145/3486952

[7] colecrouter. 2022. wooting-js. https://github.com/colecrouter/wooting-js.

[8] Christian Corsten, Bjoern Daehlmann, Simon Voelker, and Jan Borchers. 2017. BackXPress: Using Back-of-Device Finger Pressure to Augment Touchscreen Input on Smartphones. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. Association for Computing Machinery, New York, NY, USA, 4654–4666. https://doi.org/10.1145/3025453.3025565

[9] Staas de Jong, Dünya Kirkali, Hanna Schraffenberger, Jeroen Jillissen, Alwin de Rooij, and Arnout Terpstra. 2010. One-press control: a tactile input method for pressure-sensitive computer keyboards. In *CHI '10 Extended Abstracts on Human Factors in Computing Systems* (Atlanta, Georgia, USA) *(CHI EA '10)*. Association for Computing Machinery, New York, NY, USA, 4261–4266. https://doi.org/10.1145/1753846.1754136

[10] Paul H. Dietz, Benjamin Eidelson, Jonathan Westhues, and Steven Bathiche. 2009. A practical pressure sensitive computer keyboard. In *Proceedings of the 22nd Annual ACM Symposium on User Interface Software and Technology* (Victoria, BC, Canada) *(UIST '09)*. Association for Computing Machinery, New York, NY, USA, 55–58. https://doi.org/10.1145/1622176.1622187

[11] Shariff AM Faleel, Yishuo Liu, Roya A Cody, Bradley Rey, Linghao Du, Jiangyue Yu, Da-Yuan Huang, Pourang Irani, and Wei Li. 2023. T-Force: Exploring the Use of Typing Force for Three State Virtual Keyboards. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 723, 15 pages. https://doi.org/10.1145/3544548.3580915

[12] W. Fallot-Burghardt, M. Fjeld, C. Speirs, S. Ziegenspeck, H. Krueger, and T. Läubli. 2006. Touch&Type: a novel pointing device for notebook computers. In *Proceedings of the 4th Nordic Conference on Human-Computer Interaction: Changing Roles* (Oslo, Norway) *(NordiCHI '06)*. Association for Computing Machinery, New York, NY, USA, 465–468. https://doi.org/10.1145/1182475.1182538

[13] Bruno Fruchard, Paul Strohmeier, Roland Bennewitz, and Jürgen Steimle. 2021. Squish This: Force Input on Soft Surfacesfor Visual Targeting Tasks. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 219, 9 pages. https://doi.org/10.1145/3411764.3445623

[14] Min-Chieh Hsiu, Da-Yuan Huang, Chi An Chen, Yu-Chih Lin, Yi-ping Hung, De-Nian Yang, and Mike Chen. 2016. ForceBoard: using force as input technique on size-limited soft keyboard. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct* (Florence, Italy) *(MobileHCI '16)*. Association for Computing Machinery, New York, NY, USA, 599–604. https://doi.org/10.1145/2957265.2961827

[15] Jun Kato, Daisuke Sakamoto, and Takeo Igarashi. 2010. Surfboard: keyboard with microphone as a low-cost interactive surface. In *Adjunct Proceedings of the 23nd Annual ACM Symposium on User Interface Software and Technology* (New York, New York, USA) *(UIST '10)*. Association for Computing Machinery, New York, NY, USA, 387–388. https://doi.org/10.1145/1866218.1866233

[16] Elio Keddisseh, Marcos Serrano, and Emmanuel Dubois. 2021. KeyTch: Combining the Keyboard with a Touchscreen for Rapid Command Selection on Toolbars. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 191, 13 pages. https://doi.org/10.1145/3411764.3445288

[17] Yujia Liu, Qihang Shan, Zhihao Yao, and Qiuyu Lu. 2024. KeyFlow: Acoustic Motion Sensing for Cursor Control on Any Keyboard. In *Adjunct Proceedings of the 37th Annual ACM Symposium on User Interface Software and Technology* (Pittsburgh, PA, USA) *(UIST Adjunct '24)*. Association for Computing Machinery, New York, NY, USA, Article 84, 3 pages. https://doi.org/10.1145/3672539.3686348

[18] Yiyue Luo, Evelina Barhudarian, and Teddy Seyed. 2023. Project Mihr: Enabling Gestural Interactions on a Keyboard using a Graphene-based Fabric. In *Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI EA '23)*. Association for Computing Machinery, New York, NY, USA, Article 236, 7 pages. https://doi.org/10.1145/3544549.3585873

[19] David C. McCallum, Edward Mak, Pourang Irani, and Sriram Subramanian. 2009. PressureText: pressure input for mobile phone text entry. In *CHI '09 Extended Abstracts on Human Factors in Computing Systems* (Boston, MA, USA) *(CHI EA '09)*. Association for Computing Machinery, New York, NY, USA, 4519–4524. https://doi.org/10.1145/1520340.1520693

[20] Andrew P. McPherson and Youngmoo E. Kim. 2011. Multidimensional gesture sensing at the piano keyboard. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Vancouver, BC, Canada) *(CHI '11)*. Association for Computing Machinery, New York, NY, USA, 2789–2798. https://doi.org/10.1145/1978942.1979355

[21] Peter Norvig. 2012. English Letter Frequency Counts: Mayzner Revisited or ETAOIN SRHLDCU. https://norvig.com/mayzner.html.

[22] Gonzalo Ramos, Matthew Boulos, and Ravin Balakrishnan. 2004. Pressure widgets. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Vienna, Austria) *(CHI '04)*. Association for Computing Machinery, New York, NY, USA, 487–494. https://doi.org/10.1145/985692.985754

[23] Jef Raskin. 2000. *The humane interface: new directions for designing interactive systems*. ACM Press/Addison-Wesley Publishing Co., USA.

[24] Jun Rekimoto, Takaaki Ishizawa, Carsten Schwesig, and Haruo Oba. 2003. PreSense: interaction techniques for finger sensing input devices. In *Proceedings of the 16th Annual ACM Symposium on User Interface Software and Technology* (Vancouver, Canada) *(UIST '03)*. Association for Computing Machinery, New York, NY, USA, 203–212. https://doi.org/10.1145/964696.964719

[25] Yilei Shi, Haimo Zhang, Hasitha Rajapakse, Nuwan Tharaka Perera, Tomás Vega Gálvez, and Suranga Nanayakkara. 2018. GestAKey: Touch Interaction on Individual Keycaps. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3173574.3174170

[26] Stuart Taylor, Cem Keskin, Otmar Hilliges, Shahram Izadi, and John Helmes. 2014. Type-hover-swipe in 96 bytes: a motion sensing mechanical keyboard. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Toronto, Ontario, Canada) *(CHI '14)*. Association for Computing Machinery, New York, NY, USA, 1695–1704. https://doi.org/10.1145/2556288.2557030

[27] John W Tukey. 1977. *Exploratory Data Analysis*. Vol. 2. Addison-Wesley Publishing Company, Reading, MA.

[28] Ying-Chao Tung, Ta Yang Cheng, Neng-Hao Yu, Chiuan Wang, and Mike Y. Chen. 2015. FlickBoard: Enabling Trackpad Interaction with Automatic Mode Switching on a Capacitive-sensing Keyboard. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI '15)*. Association for Computing Machinery, New York, NY, USA, 1847–1850. https://doi.org/10.1145/2702123.2702582

[29] Jacob Wobbrock, Brad Myers, and Brandon Rothrock. 2006. Few-key text entry revisited: mnemonic gestures on four keys. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Montréal, Québec, Canada) *(CHI '06)*. Association for Computing Machinery, New York, NY, USA, 489–492. https://doi.org/10.1145/1124772.1124846

[30] wooting.io. 2019. Wooting Two HE. https://wooting.io/wooting-two-he.

[31] Jisu Yim, Seoyeon Bae, Taejun Kim, Sunbum Kim, and Geehyuk Lee. 2024. Palmrest+: Expanding Laptop Input Space with Shear Force on Palm-Resting Area. In *Proceedings of the 37th Annual ACM Symposium on User Interface Software and Technology* (Pittsburgh, PA, USA) *(UIST '24)*. Association for Computing Machinery, New York, NY, USA, Article 6, 14 pages. https://doi.org/10.1145/3654777.3676371

[32] Haimo Zhang and Yang Li. 2014. GestKeyboard: enabling gesture-based interaction on ordinary physical keyboard. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Toronto, Ontario, Canada) *(CHI '14)*. Association for Computing Machinery, New York, NY, USA, 1675–1684. https://doi.org/10.1145/2556288.2557362

[33] Jingjie Zheng, Blaine Lewis, Jeff Avery, and Daniel Vogel. 2018. FingerArc and FingerChord: Supporting Novice to Expert Transitions with Guided Finger-Aware Shortcuts. In *Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology* (Berlin, Germany) *(UIST '18)*. Association for Computing Machinery, New York, NY, USA, 347–363. https://doi.org/10.1145/3242587.3242589

[34] Jingjie Zheng and Daniel Vogel. 2016. Finger-Aware Shortcuts. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 4274–4285. https://doi.org/10.1145/2858036.2858355

A APPENDIX: TABLES OF STATISTICAL TESTS

This appendix presents tables of ANOVA and post hoc statistical tests for main effects and interactions of our results (Section 3.5).

A.1 Level Counts

Table A.1: Main effects for LEVEL-COUNTS.

(a) *Accuracy* ($F_{2,46} = 151.21$, $p < .0001$, $\eta^2_G = 0.76$)				
comparisons		*diff (%)*	*p-value*	
TWO-LEVELS	THREE-LEVELS	17.3	< .0001	***
TWO-LEVELS	FOUR-LEVELS	30.8	< .0001	***
THREE-LEVELS	FOUR-LEVELS	13.5	< .0001	***
(b) *Time* ($F_{2,46} = 114.3$, $p < .0001$, $\eta^2_G = 0.34$)				
comparisons		*diff (s)*	*p-value*	
TWO-LEVELS	THREE-LEVELS	-0.193	< .0001	***
TWO-LEVELS	FOUR-LEVELS	-0.41	< .0001	***
THREE-LEVELS	FOUR-LEVELS	-0.217	< .0001	***
(c) *Learnability* ($\chi^2_{2,N=24} = 39.7$, $p < 0.0001$, $W = 0.41$)				
comparisons		*diff*	*p-value*	
TWO-LEVELS	THREE-LEVELS	1.34	< .001	***
TWO-LEVELS	FOUR-LEVELS	2.38	< .0001	***
THREE-LEVELS	FOUR-LEVELS	1.04	< .01	**
(d) *Mental Demand* ($\chi^2_{2,N=24} = 36.7$, $p < 0.0001$, $W = 0.76$)				
comparisons		*diff*	*p-value*	
TWO-LEVELS	THREE-LEVELS	-1.13	< .001	***
TWO-LEVELS	FOUR-LEVELS	-2.34	< .001	***
THREE-LEVELS	FOUR-LEVELS	-1.21	< .001	***
(e) *Physical Demand* ($\chi^2_{2,N=24} = 22.4$, $p < 0.0001$, $W = 0.47$)				
comparisons		*diff*	*p-value*	
TWO-LEVELS	THREE-LEVELS	-1.17	< .001	***
TWO-LEVELS	FOUR-LEVELS	-1.75	< .001	***
THREE-LEVELS	FOUR-LEVELS	-0.58	< .05	*
(f) *Temporal Demand* ($\chi^2_{2,N=24} = 22.3$, $p < 0.0001$, $W = 0.46$)				
comparisons		*diff*	*p-value*	
TWO-LEVELS	THREE-LEVELS	-0.55	< .05	*
TWO-LEVELS	FOUR-LEVELS	-1.09	< .01	**
THREE-LEVELS	FOUR-LEVELS	-0.54	< .05	*
(g) *Performance* ($\chi^2_{2,N=24} = 27.4$, $p < 0.0001$, $W = 0.57$)				
comparisons		*diff*	*p-value*	
TWO-LEVELS	THREE-LEVELS	1.42	< .01	**
TWO-LEVELS	FOUR-LEVELS	2.21	< .001	***
THREE-LEVELS	FOUR-LEVELS	0.79	< .05	*
(h) *Effort* ($\chi^2_{2,N=24} = 35.18$, $p < 0.0001$, $W = 0.73$)				
comparisons		*diff*	*p-value*	
TWO-LEVELS	THREE-LEVELS	-1.3	< .001	***
TWO-LEVELS	FOUR-LEVELS	-2.21	< .001	***
THREE-LEVELS	FOUR-LEVELS	-0.91	< .001	***
(i) *Frustration* ($\chi^2_{2,N=24} = 19.6$, $p < 0.0001$, $W = 0.41$)				
comparisons		*diff*	*p-value*	
TWO-LEVELS	THREE-LEVELS	-0.79	< .05	*
TWO-LEVELS	FOUR-LEVELS	-1.46	< .01	**
THREE-LEVELS	FOUR-LEVELS	-0.67	.05	

A.2 Two Levels

Table A.2: *Time* main effects.

(a) KEY ($F_{7,161} = 13.91$, $p < .0001$, $\eta^2_G = 0.10$)

comparisons		*diff (s)*	*p-value*	
A	ALL OTHERS	< -0.085	< .01	**
S	K	-0.176	< .001	***
S	L	-0.123	< .001	***
F	K	-0.127	< .001	***
F	L	-0.074	< .05	*
D	K	-0.099	< .05	*
SEMICOLON	K	-0.155	< .001	***
SEMICOLON	L	-0.102	< .05	*

Table A.3: *Ease* main effects.

(a) LEVEL ($\chi^2_{1,N=24} = 22$, $p < 0.0001$, $W = 0.92$)

comparisons		*diff*	*p-value*	
FULL	LIGHT	1.8	< 0.001	***

(b) KEY ($\chi^2_{7,N=24} = 65.53$, $p < 0.0001$, $W = 0.39$)

comparisons		*diff*	*p-value*	
F	A, S, D, L, SEMICOLON	> 0.96	< .05	*
J	A, S, D, K, L, SEMICOLON	> 1.0	< .05	*

A.3 Three Levels

Table A.4: *Accuracy* main effects.

(a) LEVEL ($\chi^2(2, N = 24) = 21.21$, $p < 0.0001$)

comparisons		*diff (%)*	*p-value*	
FULL	MEDIUM	22.1	< .05	*
FULL	LIGHT	40.6	< .001	***
MEDIUM	LIGHT	18.5	< .05	*

Table A.5: *Time* main effects and interactions.

(a) LEVEL ($F_{1.57,36.10} = 13.53$, $p < .001$, $\eta^2_G = 0.03$)

comparisons		*diff (s)*	*p-value*	
FULL	MEDIUM	-0.127	< .001	***
LIGHT	MEDIUM	-0.114	< .001	***

(b) KEY ($F_{4.56,104.98} = 17.60$, $p < .0001$, $\eta^2_G = 0.08$)

comparisons		*diff (s)*	*p-value*	
A, S	ALL OTHERS	< -0.085	< .05	*
D	K	-0.148	< .001	***
D	L	-0.085	< .05	*
F	K	-0.178	< .001	***
F	L	-0.115	< .01	**
J	K	-0.133	< .01	**
SEMICOLON	K	-0.16	< .01	**
SEMICOLON	L	-0.097	< .01	**

(c) LEVEL ×KEY ($F_{14,322} = 1.98$, $p < .05$, $\eta^2_G = 0.02$)

comparisons		*diff (s)*	*p-value*	
within FULL				
A	D	-0.188	< .01	**
A	K	-0.384	< .001	***
A	L	-0.313	< .001	***
within MEDIUM				
S	F	-0.189	< .05	*
S	J	-0.237	< .01	**
S	K	-0.267	< .05	*
S	L	-0.23	< .05	*
within LIGHT				
A	K	-0.289	< .05	*
A	L	-0.209	< .01	**

Table A.6: *Ease* main effects.

(a) LEVEL ($\chi^2_{2,N=24} = 37.11$, $p < 0.0001$, $W = 0.77$)

comparisons		*diff*	*p-value*	
FULL	MEDIUM	3.21	< 0.001	***
FULL	LIGHT	3.38	< 0.001	***

(b) KEY ($\chi^2_{7,N=24} = 76.59$, $p < 0.0001$, $W = 0.46$)

comparisons		*diff*	*p-value*	
F, J	ALL OTHERS	> 1.08	< .05	*
K	L	0.88	< .05	*

A.4 Four Levels

Table A.7: *Accuracy* main effects.

(a) LEVEL ($\chi^2(3, N = 24) = 58.39$, $p < 0.0001$)

comparisons		*diff (%)*	*p-value*	
FULL	MEDIUMHIGH	61.1	< .001	***
FULL	MEDIUMLOW	42.3	< .001	***
FULL	LIGHT	35.8	< .001	***
MEDIUMLOW	MEDIUMHIGH	18.8	< .05	*
LIGHT	MEDIUMHIGH	25.3	< .01	**

Table A.8: *Time* main effects and interactions.

(a) LEVEL ($F_{3,69} = 74.83$, $p < .0001$, $\eta^2_G = 0.19$)

comparisons		*diff (s)*	*p-value*	
FULL	MEDIUMHIGH	-0.403	< .001	***
FULL	MEDIUMLOW	-0.349	< .001	***
FULL	LIGHT	-0.062	< .05	*
LIGHT	MEDIUMHIGH	-0.341	< .001	***
LIGHT	MEDIUMLOW	-0.287	< .001	***
MEDIUMLOW	MEDIUMHIGH	-0.054	< .05	*

(b) KEY ($F_{7,161} = 19.58$, $p < .0001$, $\eta^2_G = 0.07$)

comparisons		*diff (s)*	*p-value*	
A, S	ALL OTHERS	< -0.09	< .05	*
D	L	-0.119	< .05	*
F	J	-0.071	< .05	*
F	K	-0.134	< .001	***
F	L	-0.178	< .001	***
SEMICOLON	L	-0.123	< .01	**

(c) LEVEL ×KEY ($F_{21,483} = 2.80$, $p < .0001$, $\eta^2_G = 0.03$)

comparisons		*diff (s)*	*p-value*	
within FULL				
A	D	-0.223	< .01	**
A	K	-0.325	< .001	***
A	L	-0.356	< .001	***
S	K	-0.269	< .01	**
S	L	-0.3	< .001	***
F	K	-0.225	< .05	*
F	L	-0.256	< .01	**
within LIGHT				
A	K	-0.245	< .05	*
A	L	-0.391	< .01	**
S	K	-0.293	< .05	*
S	L	-0.439	< .01	**
F	L	-0.389	< .05	*
SEMICOLON	L	-0.315	< .01	**

Table A.9: *Ease* main effects.

(a) LEVEL ($\chi^2_{3,N=24} = 55.95$, $p < 0.0001$, $W = 0.78$)

comparisons		*diff*	*p-value*	
FULL	MEDIUMHIGH	4.38	< 0.001	***
FULL	MEDIUMLOW	3.88	< 0.001	***
FULL	LIGHT	2.13	< 0.001	***
LIGHT	MEDIUMHIGH	2.25	< 0.001	***
LIGHT	MEDIUMLOW	1.75	< 0.01	**

(b) KEY ($\chi^2_{7,N=24} = 64.27$, $p < 0.0001$, $W = 0.38$)

comparisons		*diff*	*p-value*	
F, J	ALL OTHERS	> 1.17	< .05	*

A.5 Participant Pressing Distance

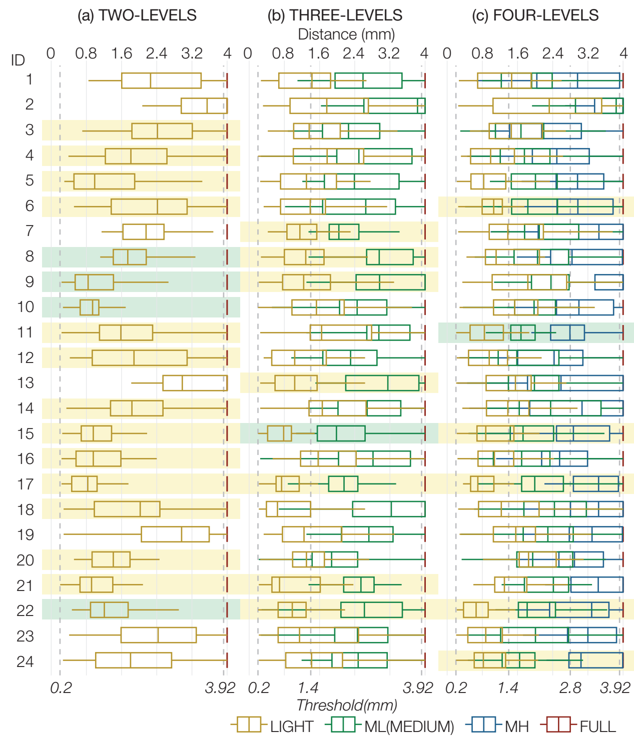

Figure A.1: The distribution of pressing distance for each LEVEL of each participant. The accuracy higher than 90% for TWO-LEVELS (17), 80% for THREE-LEVELS (8), and 70% for FOUR-LEVELS (6) is highlighted, and the highest ones are highlighted in green (100% for TWO-LEVELS, 94.7% for THREE-LEVELS, and 80.5% for FOUR-LEVELS).