# Abstract

With highly developed information technology, people have become accustomed to using virtual keyboards to type and text in various situations. In many scenarios, people need to type with only one hand and use the other hand to do other things. Nonetheless, one-handed interaction with mobile devices is influenced by multiple factors, including variations in keyboard functionality. Notably, mobile device keyboards still lack comprehensive support for one-handed typing, potentially leading to accidental touch, missed touch and other behaviors that can hinder typing efficiency. Our goal is to better understand the user experience of typing with only one hand, and to explore ways to improve the effectiveness and efficiency of typing on mobile devices with one hand. In this article, we provide a detailed description of our study along with our initial design for one-handed typing. In the past weeks, we employed a detailed survey and conducted contextual inquiries to study the potential difficulties and motivation of one-handed typing on mobile devices and developed 6 user requirements. We then established a paper prototype that contains key features such as adjusted key width, improved autocorrect, and revised punctuation keyboard. In this assignment we evaluated our paper prototype via simplified user testing and heuristic evaluation, and evaluated the results against our user requirements. The results show that our design fails to reduce recognition load and might have visibility problems in system status. We will use the analysis to build the high-fidelity prototype in the future.

# Introduction

(The previous are the same as assignment 3)

After building our paper prototype, we moved to the interactive systems evaluation section. We firstly revised the wording of user requirements to improve its testability and objectivity. Then we separately conducted heuristic evaluation with usability experts to identify usability issues with respect to the 10 usability heuristics. Our results show that we still have usability problems mainly in visibility of system status, user control and freedom, and recognition load. We also conducted simplified user testing with stakeholders to test the features and usability of paper prototype against our user requirements. In this task we encouraged the participants to ‘think aloud’ while doing the tasks and we acted as observers to watch for errors and confusions. The difficulties are to elaborately design our subtasks to reflect user requirements, as well as letting the participants to perform ‘think aloud’ during the test. Our results show that the participants still make errors and get confused when completing several subtasks, especially with the discoverability issues. We are going to fix those main issues in the next iteration. In short, we evaluated our paper prototype using simplified user testing and heuristics evaluation to get valuable feedback to improve the existing prototype. The details are specified in section 7.

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# Related Work

Isaac

# User Requirements

Rubric: Does the assignment contain updated requirements? Are those user requirements objective and testable and properly grounded in the context of use? Is each requirement properly explained and justified?

We first carefully revised each user requirement to improve its testability, objectivity, and overall wording, based on our new knowledge gained from lecture and feedback received from GSI on (see Section ?). Then, as a group, we selected three user requirements against which the qualitative user evaluations (specifically the simplified user testing) tested our design; these requirements were selected based on whether they could be feasibly evaluated using qualitative methods and our low-fidelity paper prototype (see Section ? and Section ?).

## **Improved User Requirements**

\subsection{Typos}

\textbf{User Requirement 1}: When entering text on mobile devices, user should not make more typos (slips) when operating with one hand compared to operating with both hands (U05-07, U5-08, U05-13, U05-23, U05-27, U05-29, U05-35, U01-14, U01-15, U03-04).

The user frequently made typos, in almost every other word, while typing on the phone with one hand (U05-07 to 08, U05-23, U05-35). They expressed frustration and annoyance towards making these slips (U05-13) and switched to typing with both hands when they became too irritated with making typos, even if that meant putting down the artifact that originally occupied their other hand to focus on typing (U05-27). This truly shows the level of frustration of the user with making typos. Moreover, when typing with both hands, the user experienced fewer typos compared to typing with one hand (U05-29). Taken together, it is clear that there is a salient breakdown in the existing method of one-handed text entry on mobile devices, hence this user requirement.

\subsection{Keyboard assistive feature}

\textbf{User Requirement 2}: User should not need to manually fix any results produced by the system’s keyboard assistive features (e.g., autocorrect) when entering text on their mobile device with one hand (U05-09, U05-10, U05-11, U05-12, U05-13, U05-25, U05-27, U05-30).

The autocorrect feature appears to be ineffective and even counterproductive when the user is using one hand to enter text on the phone while multitasking (U05-09 to 13, U05-25). The default autocorrect feature on the phone would automatically change the typo word to a word that the algorithm believes is what the user intended to type unless the user manually selected a suggested word displayed at the top of the keyboard (U05-09, U05-11). However, more often than not, the autocorrect feature got it wrong (U05-09), and the resulting word would sometimes be completely different from what the user intended, especially when it was an acronym (U05-10). Moreover, the user could not use the autocorrect feature on this word anymore because the word was now considered “correct” by autocorrect; consequently, the user had to manually delete and retype the entire word (U05-12). Forgetting to manually select from the suggested words was especially common when the user was using one hand and distracted by the surroundings (U05-11), causing the autocorrect to be in fact counterproductive and making the user very annoyed and frustrated (U05-13). In contrast, the user was able to use the autocorrect feature much more effectively and efficiently when typing with both hands (U05-30). Thus, it is clear that there is a breakdown in the existing autocorrect feature when entering text on the phone with one hand and multitasking.

\subsection{Keyboard layout}

\textbf{User Requirement 3}: User should be able to remove any text entered on their mobile device using one hand without accidentally removing any other characters or words the user did not intend (U05-25, U05-26, U05-27, U02-06, U04-17).

It was difficult for autocorrect to produce the right suggested words every single time, and when it did not, the user struggled to fix typos with just one hand (U05-25, U05-26, U05-27, U02-06, U04-17). In the case when the user’s other hand was occupied, they had no choice but to manually fix the typo with just one hand by first holding down the delete key, which frequently ended up over-deleting the entire current word and the word before it, rather than just up to and including the letter that differed from the right word (U02-06, U04-17, U05-26). As a result, the user had to spend more time retyping more letters than necessary. Moreover, the fact that the user would use both hands to fix the typos when the other hand was not occupied (U05-12) and even when the other hand was occupied if they became so frustrated with fixing typos (U05-27) truly indicates the difficulty of fixing typos with just one hand. Therefore, this user requirement was created.

\textbf{User Requirement 4}: User should be able to interact with all keyboard elements using one hand without slips and without straining (overextending) their thumb (hand) or repositioning the mobile device (U04-02, U04-03, U04-05, U04-06, U04-12, U01-05, U01-07, U01-13, U02-02, U02-03, U02-08, U02-17, U02-20, U03-06, U03-08, U03-12, U04-06, U04-07, U04-09, U04-10, U04-11, U05-37).

The ability to comfortably reach the edges of the keyboard appeared to be a major breakdown in one-handed text entry on mobile devices. These interpretation notes all showed that, when operating their phone one-handed in utilizing various social media and messaging services, the user had to constantly strain their thumb to reach for different keyboard elements (and other general UI elements) located at the opposite side of the users’ thumb, which was uncomfortable and frustrating. For example, some of these keyboard elements include the keyboard-switch key (U03-06, U05-37), the send/enter key (U02-02, U04-10, U04-11), capitalization key (U03-12), all of which are located on the edges of the keyboard, opposite to the user's thumb (depending on the thumb they were using to type). Moreover, as the user tried to reach the opposite end of the keyboard, they often misclicked on different keys (e.g., U02-17, U03-08, 04-11). To alleviate the discomfort, the user was sometimes forced to switch from one hand to two hands (e.g., U02-20) or reposition the device (e.g., U01-07). Users who enter text on the phone with one hand almost always need to access all keys on the keyboard with one hand. Thus, ensuring the user can comfortably and accurately interact with all elements on the keyboard one-handed is absolutely essential.

\textbf{User Requirement 5}: User should be able to locate and enter emojis, punctuations, and numbers on the mobile device with one hand faster than their default (i.e., current or existing) method of entry (U05-15, U05-16, U05-17, U05-37, U04-09, U04-18, U02-08, U03-06, U03-18, U03-19).

There appears to be a breakdown in entering non-letters with one hand, such as emojis (U05-15, U05-16, U05-17, U04-09, U04-18), punctuations, and numbers (U02-08, U03-06, U03-18, U03-19, U05-37). To enter these characters, the user had to first switch the keyboard (e.g., switching from the default letters keyboard to the emojis keyboard) by locating and pressing the keyboard-switch key, with which the user struggled since this key is located at the edge of the keyboard (U05-15, U05-37, U03-18, U03-19). Then, the user had to find the desired characters on the new keyboard, which was also hard to do: For example, to select to desired emoji, the user had to consciously look at the keyboard rather than relying on muscle memory because the emojis keyboard has way more keys (i.e., emojis to choose from) compared to the letters keyboard and it also dynamically changes based on the frequently used emoji of the user (U05-16). A similar experience applies to the punctuations and numbers keyboard (U03-18, U05-37). Furthermore, because the user had to frequently enter these characters, almost in every message they sent, this process drastically slowed down the overall text entry speed (U05-17) and the user eventually stopped entering these characters due to its complexity (U05-37).

\subsection{Physical discomfort}

\textbf{User Requirement 6}: User should be able to hold their mobile device one-handed in a secure manner without inflicting physical discomfort (U01-07, U01-08, U01-09, U01-20, U01-21, U02-09, U02-10, U03-07, U03-13, U03-14, 04-04).

The user experienced difficulty in holding the phone with one hand, as indicated by all of these interpretation notes above. The trouble of holding the phone with one hand often led to fatigue (e.g., U02-10), which consequently resulted in the user either dropping their phone or worried that they might drop their phone (e.g., U01-08, U03-07). Sometimes, the user used their pinky as a rest stand to support their mobile devices; however, it did not take long before the phone’s weight tired out the user’s pinky (e.g., U02-09). Dropping a phone can damage it and even make the phone malfunction, which hinders the users' ability to enter text. Thus, it is important to ensure that the user is able to securely and comfortably hold their phones one-handed.

## **Selected User Requirements for Qualitative User Evaluation**

We collectively decided which user requirements to evaluate our prototype against based on two criteria: The user requirement must be able to be tested (1) using qualitative user evaluation methods, and (2) using our current low-fidelity paper prototype with functionality being wizard-of-oz. This section first discussed the user requirements we eliminated because they did not meet at least one of these two criteria, then discussed the user requirements we selected, explaining how and why they would meet both criteria.

First, user requirements 1 and 6 were eliminated because they did not meet the second criterion. Evaluating user requirement 1 would require measuring the number of typos made by the participants while typing a piece of text on the prototype, which was definitely not feasible on our current paper prototype that did not have any “real” functionalities. Similarly, testing user requirement 6 would also need a high-fidelity prototype with appropriate size, weight, and surface that imitates that of a real mobile device and can stimulate the user's senses. Thus, we did not choose user requirements 1 and 6 for the current stage of user evaluation.

While user requirement 5 could be (at least somewhat) tested using a paper prototype with wizard-of-oz and we in fact, originally included it when designing the user goal and subgoals/tasks for the simplified user testing, after the lecture on quantitative user evaluation, we realized that requirements that have to do with comparison between designs (showing one design to be better than another) and measurement of speed, like that of user requirement 5, would best be tested by quantitative user evaluations. Thus, we did not include this user requirement as part of our analysis of the results of the current stage of user evaluation. The tasks that were originally designed to test this requirement were not removed because despite not being able to test this requirement, seeing how users perform on those tasks would still give us valuable insights on whether those features were usable or could be potentially helpful, such that we would possibly iterate on them and better evaluate them in the future using quantitative methods.

On the other hand, the remaining three user requirements were indeed possible to be evaluated in the current stage of user evaluation. Successfully meeting user requirement 2 would mean that the user should not consciously notice any changes made by the prototype’s keyboard assistive features. Thus, by introducing subgoals/tasks in the simplified user testing where keyboard assistive features, specifically autocorrect and autocomplete, would play a role, we would consider our design prototype to successfully meet this user requirement as long as the user did not explicitly mention anything that seemed off or counterproductive while doing those tasks. Moreover, our paper prototype already had features with appropriate frames/interactions for wizard-of-oz designed to address this requirement. Thus, this user requirement met both criteria, consequently, it was selected as one of the three requirements we tested our design against.

Likewise, user requirement 4 could also be evaluated using simplified user testing by creating various subgoals/tasks that require the user to interact with as many elements at different locations on the keyboard as possible, and if the user did not explicitly mention any difficulties (while doing think-aloud) nor show any actions that would imply any difficulties, such as long pauses, negative emotions, etc., we would consider our prototype successfully meeting this requirement. Just like previously, features that attempt to address this requirement were already implemented in the current paper prototype. Therefore, this requirement was selected for the current stage of evaluation.

To evaluate user requirement 3, we could use a task that requires the user to accurately delete some text, such as exactly one word, and in order for it to be considered as successfully met, the user should be able to use the new feature of the delete key of our prototype to delete the designated text. In contrast, using other methods or interactions such as repeatedly tapping the delete key or holding down the cursor to select the text would all be considered as not successfully meeting (or failing) this requirement since they did not use the new feature in *our* design, thus providing inconclusive evidence for whether *our* design prototype would meet this requirement. Additionally, this new feature with the relevant frames and interactions was available on the prototype and ready to be used. Hence, this requirement was also selected for the current stage of evaluation.

It was important to note that although user requirements 2 and 3 were selected because they technically met the two criteria we defined, they would still be evaluated more validly and completely using a high-fidelity prototype, since the subgoals/tasks we created for simplified user testing with discounted, low-fidelity paper prototype would be simple and restricted, which might not fully represent the user requirements. However, even with discounted usability tests like simplified user testing, we could still gain some initial insights on the usefulness of our prototype and provide at least some evidence for whether or not the user requirements were successfully met. Thus, even when we say that a user requirement was considered to be met in the results section of simplified user testing or the discussion section, it does not indicate that the prototype has no issue or room for improvement regarding features that attempt to address that requirement, it only provides evidence that we were at least somewhat in the right direction and by implementing those features in a high-fidelity prototype, we could truly better evaluate the design against those requirements.

# Heuristic Evaluation

## **Purpose**

The purpose of the heuristic evaluation was to get some initial feedback on our design, specifically regarding its usability, from usability experts via our narrow-down, low-fidelity prototype. The feedback we received can be used later to iterate on the prototype and to address its salient usability issues.

## **Method**

First, as a group, we picked one realistic, overarching user goal from the context of use that could be feasibly achieved using our low-fidelity paper prototype: “Message a friend on a mobile device using just the right hand”. This goal was then broken down into subgoals or tasks which the users would perform to accomplish the overall goal. We attempted to make these subgoals/tasks cover all three user requirements we were going to test and (almost) all of the available features of our prototype. Thus, by performing these subgoals/tasks one by one, the user would inevitably explore all parts of the prototype, thus allowing us to later evaluate whether the user requirements were met as a group. The specific subgoals/tasks were listed in the Tasks & Procedures sections and further elaborated in the Method section of Simplified User Testing. The same goal and subgoals were used for both heuristic evaluation and simplified user testing.

Next, each team member conducted a heuristic evaluation with a (different) usability expert, a student (not from our team) in EECS 593, to identify usability issues with our prototype and our design in general. During the heuristic evaluation, we demonstrated to the expert how we expect the user to interact with our prototype to accomplish the goal, and the expert rated the usability of the prototype and identified its issues with a list of usability heuristics (see more details in the Tasks & Procedures section).

After each team member concluded their individual heuristic evaluation, as a group, we consolidated the findings of the individual evaluations into one table, showing all usability problems identified and their relevant information including which expert identified the problem, the heuristic violated by the problem, and the severity of the problem. We also analyzed the table to determine which issues should be addressed immediately, so we can resolve them by iterating on the prototype in the future.

## **Tasks & Procedures**

To ensure the quality and consistency of our heuristic evaluations, each team member closely followed the protocol we created as a group, which was a bare-bones, bulleted outline regarding the overall user goal and corresponding subgoals/tasks that we planned to demonstrate using the paper prototype, and the process for conducting the heuristic evaluation. This section elaborated on the protocol, discussing it in detail while maintaining its core aspects, such that it accurately presented what each team member did to conduct the heuristic evaluation.

Each team member (referred to as *the investigator* in the remainder of this section) contacted their own usability expert via email to set up the date and time for a meeting (either online or in person).

After arriving at the meeting, the investigator and the usability expert first exchanged some information, including uniqname and group name. The investigator then briefly explained our focus and context of use (“one-handed text entry on mobile devices”) and the user goal we were going to demonstrate for this heuristic evaluation (“message a friend on a mobile device using just the right hand”). The expert was instructed to record any usability issues/problems they identified in the design/prototype with respect to the 10 usability heuristics, during the demo. The 10 usability heuristics that the expert used to evaluate the prototype are listed below.

1. Visibility of system status
2. Match between system and the real world
3. User control and freedom
4. Consistency and standards
5. Error prevention
6. Recognition rather than recall
7. Flexibility and efficiency of use
8. Aesthetic and minimalist design
9. Help users recognize, diagnose, and recover from errors
10. Help and documentation

For each usability issue identified, the expert also indicated to which heuristic the issue corresponds and rated the severity of the issue on a scale of 0 (*not a problem at all*) to 4 (*usability catastrophe*).

After the above information and instructions were clearly conveyed to the usability expert, the heuristic evaluation then began according to the instructions, with the investigator demonstrating the prototype on how the user would use it to achieve the goal, while the usability expert recorded down any usability problems they identified. Specifically, the investigator demonstrated the following subgoals/tasks one by one using the paper prototype:

1. Switch to one-handed keyboard and adjust keyboard width
2. Enter text “Cool, good”
3. Enter “luck”
4. The user realized that they accidentally made a typo, i.e., entered “lyck”, fix the typo
5. The user changed their mind and wanted to enter “kick” instead, replace “luck” with “kick”
6. Enter “!”
7. Enter 😂 emoji
8. Send the message

At any time during the demo, the expert was allowed to ask clarification questions about each subgoal/task, or the design/prototype. After the demonstration ended, the expert gave their notes, the usability problems with their corresponding information, to the investigator and briefly explained each problem. The investigator also had a chance to ask any clarification questions about the issues. The entire heuristic evaluation lasted about 30 minutes. Afterward, the investigator thanked the expert, and the meeting was concluded (Remark: Technically, the investigator and expert then switched roles because the other student had to demonstrate their prototype to us, but this was not important for our study, thus not being presented in the report).

## **Participants (Usability Experts)**

There were a total of 5 usability experts, each participating in a heuristic evaluation which a team member conducted. Their information was listed in Table ?.

| Encoding | Usability Expert | Group |
| --- | --- | --- |
| E1 (Daniel) | esing | 18 |
| E2 (Franklin) | lkurek | 3 |
| E3 (Isaac) | tonytang | 20 |
| E4 (Jerry) | pinhan | 11 |
| E5 (Yichen) | zixiangz | 20 |

# Heuristic Evaluation Results

| Usability problem | E1  Daniel | E2 Franklin | E3 Isaac | E4 Jerry | E5 Yichen |
| --- | --- | --- | --- | --- | --- |
| No indication for how to switch to the one-handed keyboard (our new design). (#10, #6, #1, #7; 4) | 2 | 3 |  | 4 | 3 |
| No indication of the extended delete key feature (#1, #10; 2) | 1 |  | 4 |  |  |
| The user still needs to touch the very left of the screen to fix the beginning words (#3; 1) | 2 |  |  |  |  |
| Need to allow users to delete characters, not just words (#7; 1) | 1 |  |  |  |  |
| Deviates from the standard keyboard layout  (#4; 1) |  | 3 |  |  |  |
| No indication users can press on the typo word to be taken to the table/list of suggested words. (#1, #6, #7; 2) |  | 3 |  | 2 |  |
| The user cannot return to the ‘ABC’ keyboard from the emoji and number/punctuation keyboard. (#4, #3; 2) |  | 3 |  |  | 3 |
| The user is locked to comma, and question mark as default for the bottom right keys (#3; 1) |  | 2 |  |  |  |
| The user cannot toggle the keyboard cosmetics/typo lists off. (#3, #5, #9; 4) |  | 1 | 3 | 3 | 3 |
| The user cannot continuously delete words with the new delete feature. (#3; 1) |  | 1 |  |  |  |
| The user can mistakenly minimize the keyboard for one handed use by accidentally dragging the keyboard. (#5; 1) |  |  | 1 |  |  |
| The user does not know you can swipe up to type an exclamation mark. (#10; 1) |  |  | 4 |  |  |
| No apparent limit to the keyboard minimization feature. (#3; 1) |  |  | 2 |  |  |
| The animation of extended delete key and disabled letter keys being triggered every time the delete key is pressed is not only initially confusing to new users, but also annoy experienced users. (#1, #7; 1) |  |  |  | 2 |  |

# Simplified User Testing

## **Purpose**

The purpose of the simplified user testing was to get some initial feedback on our design, specifically regarding both its usefulness and usability, from real stakeholders via our narrow-down, low-fidelity prototype. The feedback we received allows us to not only realize the usability issues regarding our prototype, but also to better understand the context of use and whether our design addresses the user requirements, so we can later iterate on the prototype to improve it.

## **Method**

***Goal and subgoals/tasks***

The same user goal and the corresponding subgoals/tasks from heuristic evaluation were used for the simplified user testing (see more in the Tasks & Procedures section). To briefly reiterate, we collectively picked one user goal (“Message a friend on a mobile device using just the right hand”) and broke it down into subgoals/tasks, which were realistic, concrete, and grounded in the context of use. By doing the tasks, the user would test out different features of the prototype, giving us the information we need to evaluate our design prototype against the three selected user requirements. The tasks are listed below with the explanation on how they were created and the corresponding user requirement(s) it attempts to measure.

1. Switch to one-handed keyboard & adjust keyboard width
2. Enter text “Cool, good”
3. Enter “luck”
4. You realized that you accidentally made a typo (i.e., entered “lyck”), fix the typo
5. You changed your mind and wanted to enter “kick” instead, replace “luck” with “kick”
6. Enter “!”
7. Enter 😂 emoji
8. Send the message

To begin, the purpose of Task 1 was not to test any specific user requirements, but to make sure that the remaining tasks would be carried out using our one-handed keyboard design rather than the existing two-handed keyboard, since we would like to evaluate *our* new design not the existing one.

Task 2, 6, and 7 were originally designed to test user requirement 5, which involves the user entering punctuation and emoji efficiently. However, because we later realized that this requirement could not be evaluated in the current stage as it would involve measurement of speed, which works best with quantitative evaluation, these tasks were no longer considered to be testing this requirement. However, knowing how the participants perform on these tasks could still give us some initial insights on whether these new features of our design prototype would be promising and may potentially meet this requirement in the future when tested with quantitative methods.

Task 3 and 4 attempted to evaluate our prototype against user requirement 2: “User should not need to manually fix any results produced by the system’s keyboard assistive features (e.g., autocorrect) when entering text on their mobile device with one hand.” These two tasks imitate the scenario where a user accidentally made a slip resulting in a typo. This is a common scenario frequently found in our contextual inquiry. In this case, autocorrect would be counterproductive by automatically changing the word to another word which the user did not intend to type. Our design attempted to address this requirement by offering the user the freedom to conveniently choose whether to use autocorrect or not, and this user requirement would be considered fulfilled if the user were able to find and select the word they want to replace the typo with in the suggestion table, had they chosen to use this feature. This would indicate that our design met user requirement 2, at least to a certain extent given the current user testing with discounted prototype.

Task 5 attempted to evaluate our prototype against user requirement 3: “User should be able to remove any text entered on their mobile device using one hand without accidentally removing any other characters or words they did not intend.” This task involved the user to accurately delete one word on the prototype using one hand, which exactly parallels the user requirement itself. In order to consider our design to meet this requirement, the user would need to correctly utilize the new feature to delete the desired word. If the user used any existing features like repeatedly pressing the delete key or holding down the cursor to select the word, it would be considered not satisfying this user requirement. This is because we wanted to evaluate our new design, not the existing technology.

Lastly, all tasks except task 1, when taken together, attempted to evaluate our prototype against user requirement 4: “User should be able to interact with all keyboard elements using one hand without slips and without straining (overextending) their thumb (hand) or repositioning the mobile device.” By having the user interact with various elements at different locations on the keyboard, we can see whether the user explicitly mentioned or showed any actions that would imply any difficulties, such as long pauses or negative emotions, during the think-aloud. If none of them were present, we would consider our prototype to meet this user requirement, at least to some extent.

***Stakeholders***

After creating the tasks for the users to perform, each team member then conveniently recruited a participant from the stakeholder group for the simplified user testing according to the inclusion/exclusion criteria we defined as a group: The participant 1) must be at least 18 years old, 2) right-handed or primarily use their phone with the right hand, and 3) preferably uses an iPhone (Note: the last criterion is preferred but not required).

***Conducting user testing***

Each team member then individually conducted simplified user testing with their participant following the protocol we designed collectively as a group (see specific details/steps of the protocol in the Tasks & Procedures section). Participants used the prototype, with its functionality being wizard-of-oz by the team member, to do each subgoal/task which all taken together accomplish the user goal, while performing a think-aloud by constantly talking and verbalizing their thoughts as they move through the user interface. The think-aloud allows investigators to understand not only what the participants were doing, but also what they were thinking, which may reveal additional insights on the prototype’s issues, leading to a better evaluation of the prototype’s usability and usefulness.

***Analysis***

Each team member took notes during (and after) their simplified user testing, regarding the interpretations of the participant’s actions and utterances during the think-aloud in relation to the prototype’s usability and usefulness. Then, as a group, we consolidated the notes to produce high-level findings demonstrating our design’s usability and whether it met the three user requirements we selected for the evaluation. With the analyses of the findings, we can improve our design by iterating on the prototype in the future.

## **Tasks & Procedures**

To ensure the quality and consistency of our simplified user testing, each team member closely followed the protocol we created as a group, which was a bare-bones, bulleted outline regarding the process for conducting the simplified user testing, and the overall user goal and the corresponding subgoals/tasks which the participants had to perform. This section elaborated on the protocol, discussing it in detail while maintaining its core aspects, such that it accurately presented what each team member did to conduct the simplified user testing.

Each team member (referred to as *the investigator* in the remainder of this section) contacted their own participant online, by sending a message inviting them to participate in a user testing study on a design prototype. The message roughly described what the study was about, using a prototype to perform some tasks while narrating their thoughts; estimated duration, 30 minutes; required qualifications (inclusion/exclusion criteria defined early); and that the study had to be recorded (if the investigator needed to). After obtaining the participant’s initial confirmation that they met the qualifications and were willing to do the testing, the participant and the investigator arranged an in-person meeting.

Upon arrival at the meeting and before starting the user testing, the participant was once again informed about the purpose of the study, to evaluate the design prototype’s usability and usefulness, and their responsibilities, to use the prototype to execute a series of short tasks, while performing think-aloud. They were assured that their participation was fully voluntary as they may quit the study at any time. They were also told that the study would be recorded for further analysis (if needed by the investigator) and the data collected from the study would be completely anonymous and confidential. The participant then gave their verbal consent to participate in the user testing had they agreed to all of the conditions mentioned, which they did.

Starting the user testing, the investigator first clearly conveyed and explained the following instructions to the participant. Their overall goal was to “message a friend on a mobile device using just the right hand” (the same goal as heuristic evaluation). They would be given one subgoal/task at a time, which they need to execute on the prototype using just their right hand; completing all of the tasks would result in accomplishing the goal. While using the prototype, they had to perform think-aloud, or in other words, constantly talking and verbalizing their thoughts as they moved through the user interface. A short video was played to the participant to show them an example of think-aloud, for them to better understand what is expected (Link to video: <https://www.nngroup.com/articles/thinking-aloud-demo-video/>).

After the participant indicated that they understood the instructions clearly, the investigator gave the participant (the first frame of) the paper prototype and their first task (while starting the recording if the investigator needed to).

The paper prototype (built and discussed in the previous stage of user-centered design) had 16 frames, each resembling the size of a regular-model iPhone printed on paper and placed on a portable hard surface (with the same/similar size as the frame) such that the participant may hold it with their right hand just like how they would normally hold their phone. As the participant correctly interacted with the prototype (e.g., pressed the expected key on the current frame), the investigator would switch the current frame with the next frame, successfully giving functionality to the paper prototype with wizard-of-oz (the order/flow of frames was presented in Section 6.5).

As the participant tried to execute the first task on the prototype with their right hand while doing think-aloud, the investigator also took notes on the participant’s errors, long stalls, confusion, unexpected paths, statements of distress, and unexpected events and use, indicated by both their actions and the utterances of their thoughts. If the investigator recorded the user testing session, they would also be able to watch the recording later to pick up the details they potentially missed the first time. The investigator also wrote down any questions that they wanted to ask the participant (e.g., Why did you do this action?); these questions were deferred until the end of the user testing (after all tasks were completed). The investigator did not interrupt the participant or ask any questions during the think-aloud because that may introduce extra cognitive load to the participant. Whenever the participant reduced in frequency of think-aloud, or in other words, they stopped talking but they continued to interact with the prototype, the investigator would prompt the participant to “please keep talking”.

After the participant completed the current task, or when the participant had spent a long time on the current task yet still could not figure out how to complete it, the investigator would give them the next task to do. This process continued until all of the tasks had been given to and completed by the participant. The subgoals/tasks that the participant executed on the prototype were the following (listed in the order they were given to the participant).

1. Switch to one-handed keyboard & adjust keyboard width
2. Enter text “Cool, good”
3. Enter “luck”
4. You realized that you accidentally made a typo (i.e., entered “lyck”), fix the typo
5. You changed your mind and wanted to enter “kick” instead, replace “luck” with “kick”
6. Enter “!”
7. Enter 😂 emoji
8. Send the message

After all tasks were given to and executed by the participant, the investigator asked some follow-up questions they had during the think-aloud to the participant. In total, the simplified user testing study lasted about 30 minutes. Once the study was concluded, the investigator thanked the participants for their time.

## **Participants**

A total of five participants were conveniently selected, one for each simplified user testing we conducted individually. Each team member sent out invitations to participate in the interview online to close friends who met the inclusion/exclusion criteria for the stakeholder group (defined in the Method section). No monetary incentives were provided for the completion of the study. The demographic information about the participants are listed in Table ?. For the results and analysis, each participant was assigned with an encoding from U1 to U5 respectively.

| User encoding | Age | Gender | Race | Employment status | Dominant hand | Phone brand | Multi-lingual | Disability |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| U1  (Daniel) | 20 | Man | Asian | Student | Right | iPhone | Yes | No |
| U2  (Franklin) | 23 | Man | Asian | Student | Right | iPhone | Yes | No |
| U3  (Isaac) | 22 | Man | Asian | Student | Right | iPhone | Yes | No |
| U4  (Jerry) | 22 | Man | Asian | Employed part-time | Right | iPhone | Yes | No |
| U5  (Yichen) | 22 | Woman | Asian | Employed full-time | Right | iPhone | Yes | No |

# Simplified User Testing Results

This section will discuss the notes written down by the interviewer during the think-aloud. The notes will discuss how well the participants performed in each task and when the design failed to help the participants meet the user requirements.

**Task 1: Switch to one-handed keyboard & adjust keyboard width**

All five participants struggled to complete this task. The participants either gave up on finding the one-hand keyboard or found the feature by randomly interacting with the keyboard. Most participants expressed their frustration via think-aloud by commenting that there was no indication of how to switch to the one-handed keyboard. Additionally, they demonstrated their confusion via random interactions on the keyboard (e.g., clicking on the language-switch key, dragging on the keyboard from left to right, going to settings, etc.) and eventually turning into long stalls.

Although these results do not imply the design failed to meet any specific user requirements, not being able to switch to our one-handed keyboard design would prevent the user from utilizing any of its features. Thus, in the next iteration, our team plans to add some indicators to help improve the discoverability of the switching to one-handed keyboard interaction to ease this process for users.

**Task 2: Enter text “Cool, good”**

All participants completed this task without experiencing any significant difficulties. Everyone was able to use our one-handed keyboard design to successfully enter the words. Nobody made anything about the smaller key size being an issue, except one participant (U5) who said that they tried to be more careful by typing slower because of the smaller key size. But this does not directly indicate any issues with the key sizes.

As for the punctuation (the comma), four out of five participants immediately found the new comma key located at the bottom right or the keyboard and proceeded to use the new comma key to enter the comma, with one participant (U4) explicitly mentioning that they really liked this new feature because it made the process of entering punctuation marks much simpler. Only one participant (U5) went for the punctuation keyboard out of habit, but they later found the new comma key. The participant mentioned that if he had seen the comma key earlier, he would have definitely used the comma key. Despite not being able to assess our fifth user requirement, we see that the addition of the punctuation keys was overall well-received and made text entry easier for the user.

These results also provide some *partial* evidence for meeting user requirement 4, as the participants did not struggle with accessing and interacting with any keyboard elements utilized in this task. This demonstrates some preliminary insight into how the design might be allowing users to comfortably interact with different elements on the keyboard, potentially addressing this user requirement. However, results from other tasks would still be needed, serving as more evidence, in order to have a more confident conclusion that our design prototype really meets this requirement.

**Task 3: Enter “luck” (but accidentally typed “lyck”)**

All five participants were able to complete this task without any issues.

**Task 4: User realized that they made a typo (i.e., entered “lyck”), fix the typo**

The initial reaction was to immediately delete the word with the backspace key. When asked to perform the task again but this time without the backspace, the participants were able to discover the new autocorrect feature. All participants tapped the underlined word to open the list of nine possible words. The participants were able to easily tap the correct word using one hand. Despite the initial attempt, all participants were able to fix the typo without any issues. Additionally, users found the desired word without having to correct the new autocorrect feature. Thus, the user requirement 2 is met.

**Task 5: Replace “luck” with “kick” by deleting the word “luck”**

Almost all participant’s initial action was to delete the word “luck” letter by letter. With the exception of only one participant, everyone pressed the delete button four times to delete the word “luck”. Despite the delete key being elongated to show the user that swiping left on it could be used to delete an entire word, all participants did not know that this feature existed. Therefore, it can be concluded that this feature has low discoverability. Relating back to the user requirement, task 5 of the simplified user testing was unable to evaluate user requirement.

**Task 6: Enter “!”**

There were mixed results for task 6. One participant found that it’s more time consuming to hold the bottom right key and swipe up when compared to just switching to the numbers keyboard. All participants initially did not know that this feature existed, and needed to examine the keyboard to search for the “!” button, as it was quite a small symbol on the keyboard. This is an issue that needs to be worked on in next iterations.

**Task 7: Enter** 😂 **emoji**

Most participants found the adjustable emoji keyboard to be more comfortable and efficient to use. However, one participant found that the emoji search bar might impact the efficiency of entering emojis. This indicates a potential area for improvement in meeting requirement 5, However, the consensus here is that our adjustable emoji keyboard aligns with user requirement 5.

**Task 8: Send the message**

All five participants were able to complete this task without any issues.

# Discussion

We can conclude that the general ideas of our keyboard features are deemed promisingly usable. No user or usability expert expressed any severe concern with the core ideas of our design. However, there were still many loose ends that we did not tie up with this iteration.

The evaluations we conducted revealed that there were many small details that our paper prototype glossed over, which ended up becoming relatively serious usability issues. We were missing some signifiers and metaphors for our keyboard features which are currently lacking discoverability, and we were missing some features regarding user agency (missing a few “go back” buttons, etc).

The heuristics evaluation results show a variety of usability issues that can be boiled down to missing signifiers for specific features, lacking user agency due to missing keys in our design, and some features’ effects being ambiguous and lacking refinement. Among these, the missing signifiers/indicators are generally ranked with the highest severity of ‘4’, whereas the other ones mentioned usually yield a ‘3’ or occasionally a ‘2’. These are the issues that we should address for our next iteration.

Our simplified user testing results also reflected these issues by instantiating these scenarios. All of our participants had trouble discovering some of our features due to missing signifiers and it complicates our ability to evaluate whether our features satisfy our requirements since they were not able to use it without us intervening. In the case where they did accidentally discover our feature (e.g. the delete key), they were confused by its visuals and its vague effects. Both of these two scenarios imply a great gap of execution and a great gap of evaluation respectively.

Features attempting to satisfy user requirements 2, 3 and 4 all had usability issues from the heuristics table. The participants were able to accomplish the task related to user requirement 2 despite having a usability issue (e.g. not able to exit from a certain state after the task is done), and consider requirement 2 to be partially satisfied. For user requirement 3, we consider it not satisfied because the feature is not discoverable, and therefore the users could not even initiate the task. For user requirement 4, the feature is also not discoverable but they were able to finish the tasks because those tasks are premised on the feature being activated already. Although we consider requirement 4 to be satisfied, we need to continue working on fixing the visibility issues in our next iteration.

For our next iteration, what we need to do is fixing the most blatant visibility/discoverability issues, and run an audit on the frame states of our prototype to make sure the user can return to the default state of the keyboard regardless which other state they are in. We also want to refine the effects of some features to make them more usable and less ambiguous as to what they are supposed to do.

# Conclusion

Our previous survey into one-handed text messaging on mobile devices provided foundational insights that set the stage for our subsequent research. Among the 27 participants, it was evident that one-handed typing is a prevalent method on smartphones. However, it came with its challenges: users found it less comfortable, more challenging, and slower than two-handed typing. This highlighted potential limitations in current smartphone keyboard designs and emphasized the practical importance of our research.

Building on this foundation, our detailed contextual inquiry further illuminated the differences of one-handed text messaging. We discovered that the existing keyboard layout often poses challenges, especially when users are multitasking. The challenges users face with current keyboard layouts, autocorrect features, and the act of switching between different keyboard modes have informed 6 specific user requirements. These requirements will be crucial in guiding the design of future mobile keyboards optimized for one-handed use.

Based on the specific requirements, we derived our initial design as the low-fidelity paper prototype. We also designed several design critiques and iteratively optimized our prototype. Our design mainly established and focused on the ‘sqush’ and ‘scroll’ method so users can comfortably reach all key elements with one hand. Our design also retains most of the traditional QWERTY keyboard layout, ensuring users face a minimum learning curve as well as solving main challenges in one-handed typing.

We conducted heuristic evaluation and simplified user testing to evaluate our prototype. Both heuristics evaluation and simplified user testing reveal nearly the same issues. Based on the result, we promise to say that there are nearly no severe usability issues with the core ideas but there are still some features that lack discoverability and visibility. Though all of our user requirements have some usability issues, we at least pass two-thirds of user requirements based on our discussion. We are going to fix those issues in our next iteration.

In conclusion, the knowledge generated from our initial survey, contextual inquiries, low-fidelity paper prototype, and interactive system evaluation serves as a robust foundation for future work. It not only provides insights and potential solutions into the current challenges users face but also guides the high-fidelity prototype and product creation. We are optimistic that future researchers and designers will leverage these findings, leading to innovations that cater to the evolving needs of one-handed mobile device users.