Design and Usability Analysis of the mini-QWERTY Soft Keyboard on the iPhone 6

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Abstract

Text input is one of the most frequent tasks in human-computer interaction (Zhai & Kristensson, 2012). With the advent of mobile technology, this common and essential activity has migrated from large, stationary computing devices (e.g. typewriter), to small, touchscreen-based mobile devices (e.g. iPhone) (Romano, Paolino, Tortora, & Vitiello, 2014). The most common tool for text input on mobile devices is the mini-QWERTY soft keyboard (Zhai & Kristensson, 2012). This miniaturized, touchscreen version of the ubiquitous QWERTY physical keyboard—considered the “standard” for text entry since the late 1800s—suffers from a host of usability issues (Cooper, 1983; Zhai & Kristensson, 2012). While the standard QWERTY keyboard is suitable for text entry via computer, its mobile derivative is non-ergonomic, inefficient, inaccurate, and more cognitively demanding. This is largely due to the fact that the standard QWERTY keyboard was designed for a different technology and form factor, with different constraints, interaction styles, and contexts of use.

This paper will discuss the history and design of the standard QWERTY physical keyboard, providing a foundation upon which to understand and assess the design of its mobile derivative. The paper will then identify and explain key usability issues with the mini-QWERTY soft keyboard on the iPhone 6. It will conclude with a brief summary of possible design improvements that could be made, as well as alternative text entry mechanisms, and suggested future design and research directions.

Keywords: QWERTY keyboard, typewriter, iPhone

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Developments in processing power, storage capacity, and industrial materials have led to the creation of small, mobile computing devices (e.g. smartphones), capable of performing tasks previously reserved for computers (Manresa Yee, Más Sansó, Larrea, & Capa Arnao, 2012). Chief among these tasks are text-based communication (e.g. texts, emails) and information access (e.g. web browsing) (Romano et al., 2014). Today's smartphone users not only rely upon this functionality, they demand it (Romano et al., 2014). For that reason, it is essential that smartphones provide an effective and efficient means of accomplishing these text-based tasks, without imposing undue cognitive load on the user (Zhai & Kristensson, 2012).

The mini-QWERTY soft keyboard—a miniature, touchscreen version of the QWERTY physical keyboard developed for the Sholes and Glidden typewriter in the late 1800s—is the most common method of text entry in today's smartphones (Song, Ryu, Bahn, & Yun 2011; Zhai & Kristensson, 2012). While the QWERTY physical keyboard was, and continues to be, the "standard" for text entry, it is only suitable for certain use cases, specifically those for which it was designed (i.e. as a two-handed, text input mechanism for stationary computing devices) (Cooper, 1983; Zhai & Kristensson, 2012).

Mobile devices utilize new, more sophisticated technology, with a form factor, interaction style, context of use, and constraints that are radically different from that of early typewriters, or even modern desktop computers (Manresa Yee et al., 2012). Utilizing the QWERTY keyboard on smartphones—albeit a miniaturized, touchscreen version—is, therefore, problematic, resulting in lower user performance (e.g. lower text entry speed, higher error rates) and imposing higher cognitive load than the standard QWERTY keyboard. This poor performance is largely due to mini-QWERTY's size (i.e. small, closely spaced keys), lack of tactile feedback (i.e. keyboard does not support blind keying, demands high levels of visual attention), and ill-suited configuration (e.g. keyboard is not optimized for single finger or thumb-based typing, common characters are located in hard to reach sections of UI, common letter pairs are located on separate halves of the keyboard).

This paper analyzes and explains the design, context of use, and usability of the mini-QWERTY soft keyboard, contrasting it with that of the QWERTY physical keyboard. While the mini-QWERTY keyboard is utilized by all of the major smartphone manufacturers, this paper will specifically critique the version utilized on Apple's iPhone 6.

The paper will conclude with a brief summary of possible design improvements that could be made, as well as alternative text entry mechanisms, and suggested future design and research directions.

Design and History of the QWERTY Keyboard

In order to assess and understand the mini-QWERTY soft keyboard, it is important to analyze the history, technical constraints, context of use, design motivations, strengths, and weaknesses of its parent keyboard: the QWERTY physical keyboard.

The QWERTY physical keyboard was developed and patented by Christopher Latham Sholes and two colleagues in 1868, as part of the Sholes and Glidden typewriter (Figure 1) (Cooper, 1983). The keyboard derives its name from the left to right arrangement of keys on its second row (Q-W-E-R-T-Y) (Figure 2) (Weiss, 2002; Kay, 2013). It featured four, slightly offset rows of 11 characters each (Capobianco, Lee, & Cohen, 1999). Each character on the keyboard was connected to a long metal typebar (Cooper, 1983). When the key was depressed, the typebar swung up and transferred the character to the printed page (Kay, 2013). Since adjacent typebars were prone to jamming when hit in quick succession, historians speculate that Sholes designed the keyboard layout to ensure that common letter pairs (e.g. "TH" "ON" "AN") were separated by at least one typebar (Joyce & Moxley, 1988; Rehr, 1997; Lundmark, 2002). However, since documentation around the invention is poor, these beliefs, while commonly held and logical, cannot be verified (Rehr, 1997). A secondary belief, supported by the research, is that Sholes also designed the layout to enable salesmen to impress customers by rapidly typing out the brand name “type writer”, the characters of which can all be found in the QWERTY row (David, 1985).

Figure 1. Sholes and Glidden typewriter. Reprinted from Herkimer County Historical Society. (1923). The Story of the Typewriter 1873-1923. New York: Herkimer.

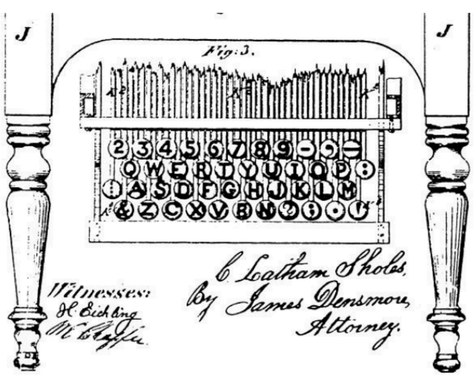

Figure 2. QWERTY key layout. Reprinted from U.S. patent #207,557.

In 1873, the Sholes typewriter was rebranded the “No. 1 Remington” when its was purchased by gunsmith E. Remington and Sons (Wershler-Henry, 2005). Remington sold and marketed the device, attracting the attention of professional writers, such as Mark Twain, who were among the first to adopt it (Cooper, 1983). The market for typewriters soon expanded rapidly, spurred by the expanding U.S.

market, which necessitated more efficient and uniform modes of communication (Cooper, 1983). Technical innovations, such as the introduction of the shift key for upper and lower case letters, and the introduction of an electric motor drive, only increased the device's appeal, functionality, and efficiency (Cooper, 1983).

Methods of Typewriting

In contrast to modern touch typing, early typists utilized a "hunt and peck" method, using a single finger from each hand to tap the various keys (Cooper, 1983). It was not until 1900 that the modern, two-handed/all finger, blind keying approach was widely adopted by typewriting schools, and later the general public (Cooper, 1983). This was due to its demonstrated speed and lower fatigue factor (Cooper, 1983).

Competing Typewriter and Keyboard Layouts

Early Competition. Though competing typewriter models, with different keyboard layouts, existed (e.g. Blickensderfer), these failed to take hold for a variety of reasons (Kroemer, 2010). Chief among these were the challenges of rearranging the mechanical linkages to work smoothly with alternative layouts, as well as users' growing familiarity and competence with the QWERTY keyboard (Kroemer, 2010). The latter was largely due to Remington's large manufacturing capacity, market share, and overall domination of the typewriter market (Kroemer, 2010; Buzing, 2003). Other QWERTY alternatives, such as the double keyboard and the chord keyboard, also failed to be adopted due to the amount of training and memorization required to operate them (MacKenzie & Tanaka-Ishii, 2007). Rather than differentiate themselves, competitors sought to mimic Remington's design (Kroemer, 2010).

Even with the inventions of the IBM Selectric typewriter and modern computer in the mid to late 20th century, both of which eliminated the jamming issue entirely, and afforded designers greater flexibility in creating alternative keyboard layouts, QWERTY remained (Kay, 2013).

Dvorak Simplified Keyboard. The only serious competitor to QWERTY has been the Dvorak Simplified Keyboard, created in the early 1930s (Cooper, 1983). Figure 3 offers a comparison of the two layouts.

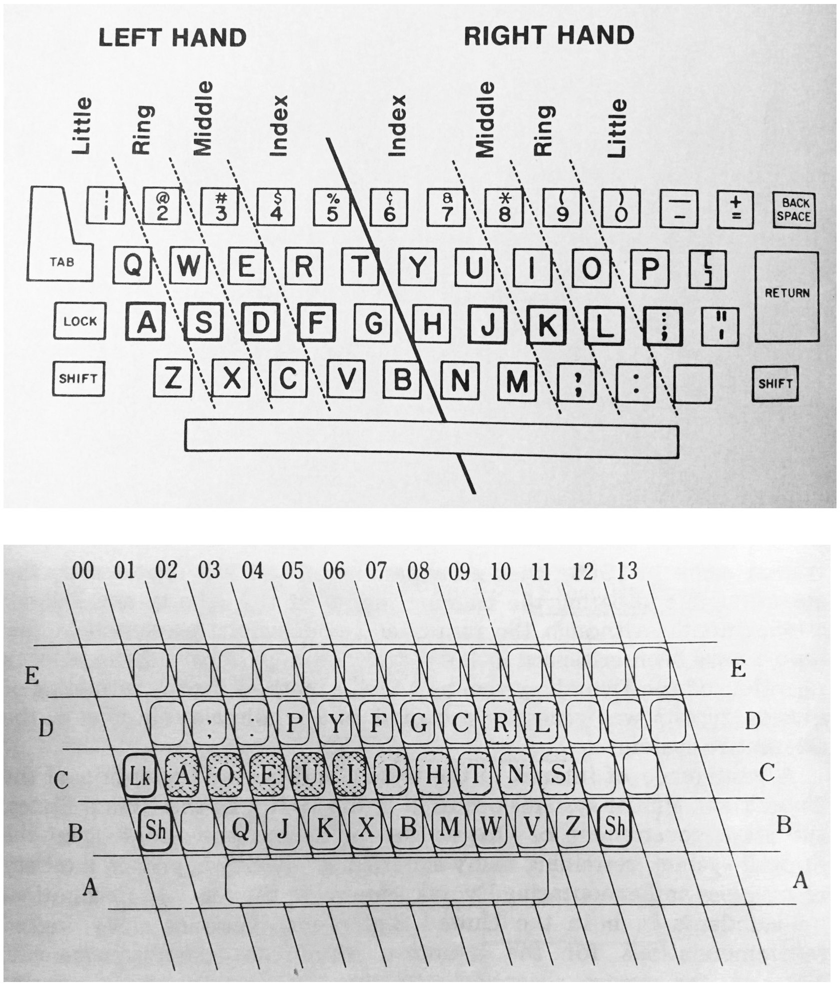

Figure 3. QWERTY (top) vs. Dvorak Simplified Keyboard layout (bottom). Reprinted from Cooper, W. E. (Ed.). (1983). *Cognitive aspects of skilled typewriting*. Springer Science & Business Media.

The Dvorak keyboard was purported to offer a number of benefits over QWERTY. These included a larger home row “vocabulary”, containing 3000 vs. 100 common words, greater usage of the right hand for the majority right-handed user population, greater utilization of all of the fingers in each hand, and a minimization of awkward fingering sequences (Cooper, 1983; David, 1985). While early studies espoused Dvorak’s superiority (e.g. Dvorak, Merrick, Dealey & Ford, 1936; Strong, 1956), academics have since criticized the studies’ methodology and rigor (Liebowitz, Margolis, & Lewin, 2002). At best, the research is inconclusive, with more recent studies recording a very modest 5% performance improvement of Dvorak over QWERTY (Norman & Fisher, 1982). Liebowitz and Margolis (1990) have even gone so far as to state that "there is no scientifically acceptable evidence that Dvorak offers any real advantage over QWERTY."

QWERTY Touch Typing Keyboard Design

Strengths. Research has shown that QWERTY was and is an efficient and effective design solution for stationary computing devices, such as typewriters and computers (Liebowitz, Margolis, & Lewin, 2002; Kay, 2013). While Dvorak is superior in terms of balancing workload between the two hands, and maximizing load on the home row, QWERTY excels in other respects (Norman & Rumelhart, 1983). For instance, it alternates more frequently between hands, allowing one hand to prepare to type the next character while the other hand is pressing a key (Norman & Rumelhart, 1983). It has also outperformed various random and alphabetical keyboard layouts in testing (Capobianco, Lee, & Cohen, 1999).

More generally, physical keyboards such as QWERTY, provide users with tactile feedback as to if and what keys have been pressed (Park et al., 2008). This facilitates blind typing, enabling the user to focus their visual attention on the text display field, as opposed to alternating between the keyboard and the display (Park et al., 2008).

Weaknesses. QWERTY, however, is not without its drawbacks. It has been criticized for its one-to-one key to character mapping, resulting in "too many keys," as well as the clear mismatch between the QWERTY layout and the natural postures of the keyboarder (Kroemer, 2010). It also requires a high level of motion and effort to activate a single key (Rempel, 2008). For a comprehensive overview of the this literature, see Kroemer (2010).

The QWERTY keyboard's standard size—typically 700mm wide from the tab to enter key—benefits manufacturers and minimizes adjustment issues when users switch between keyboards on various devices (Yoshitake, 1995). However, since hand and finger sizes vary, the keyboard supports some users better than others (Yoshitake, 1995). For that reason, Yoshitake (1995) and Sakamura (1987) advocate for at least three keyboard sizes (small, medium, and large) that can better accommodate user anatomical differences.

Despite these criticisms, QWERTY has achieved reasonably high levels of user performance and satisfaction among computer users (Matia, MacKenzie, Buxton, 1996). Claims of vastly superior keyboard alternatives remain unsupported (Cooper, 1983; Kay, 2013).

The mini-QWERTY Soft Keyboard

Development of the mini-QWERTY Soft Keyboard

Following Sholes typewriter, there were numerous technological innovations that led to the development of modern computers (Manresa Yee et al., 2012). Over the span of four decades, computers decreased in size from the PDP-1, which occupied a small room, to the Apple II desktop computer, to laptops, to today's handheld mobile devices (Kroemer, 2010).

Mobile devices underwent their own evolution, shown in Figure 4. They decreased in size, while increasing in portability, processing power, functionality, connectivity, and importance in the lives of every day users (Manresa Yee et al., 2012; Henze, Rukzio, & Boll, 2012). This led to the emergence of the "smartphone", which facilitated on-the-go text communication (e.g. texts, emails) and, later, internet access and browsing (see Cecere, Corrocher, & Battaglia, 2015 for a detailed account).

Figure 4. The evolution of the cellphone, from the car phone to the smartphone (Wall Street Journal, 2012)

Mobile devices initially utilized keypads—with multiple alphabetic characters on each numerical key—gesture-based handwriting recognition via a stylus (e.g. Palm Pilot), and miniature QWERTY physical keyboards (e.g. Blackberry). It was not until 2007, when the Apple iPhone was introduced, that touchscreens became popular, see Figure 5 (Cecere, Corrocher, & Battaglia, 2015). The introduction of the iPhone was an inflection point for the industry, with its powerful iOS operating system, large touchscreen display, and mini-QWERTY soft keyboard (Cecere, Corrocher, & Battaglia, 2015).

Figure 5. From left to right, the Nokia 1011 phone with keypad (1992), Palm Pilot Personal with stylus pen for drawing character keystrokes (1997), the Blackberry 5810 with miniature QWERTY physical keyboard (2002), and the first generation iPhone (2007). Reprinted from CNET.com, Wikipedia, CNET.com, and Time.

Overview of the mini-QWERTY soft keyboard

Instead of physical keys, the mini-QWERTY soft keyboard is displayed virtually on the smartphone touchscreen, and is manipulated via fingers or thumbs. It utilizes two keyboard layouts, seen in Figure 6, that the user can toggle between while typing (Toropainen & Ojala, 2008). The first layout offers the same alphabetic layout as a traditional QWERTY physical keyboard, while the second layout focuses on numbers and symbols, with select keys that were deemed unnecessary for mobile missing (e.g. tab) (Toropainen & Ojala, 2008).

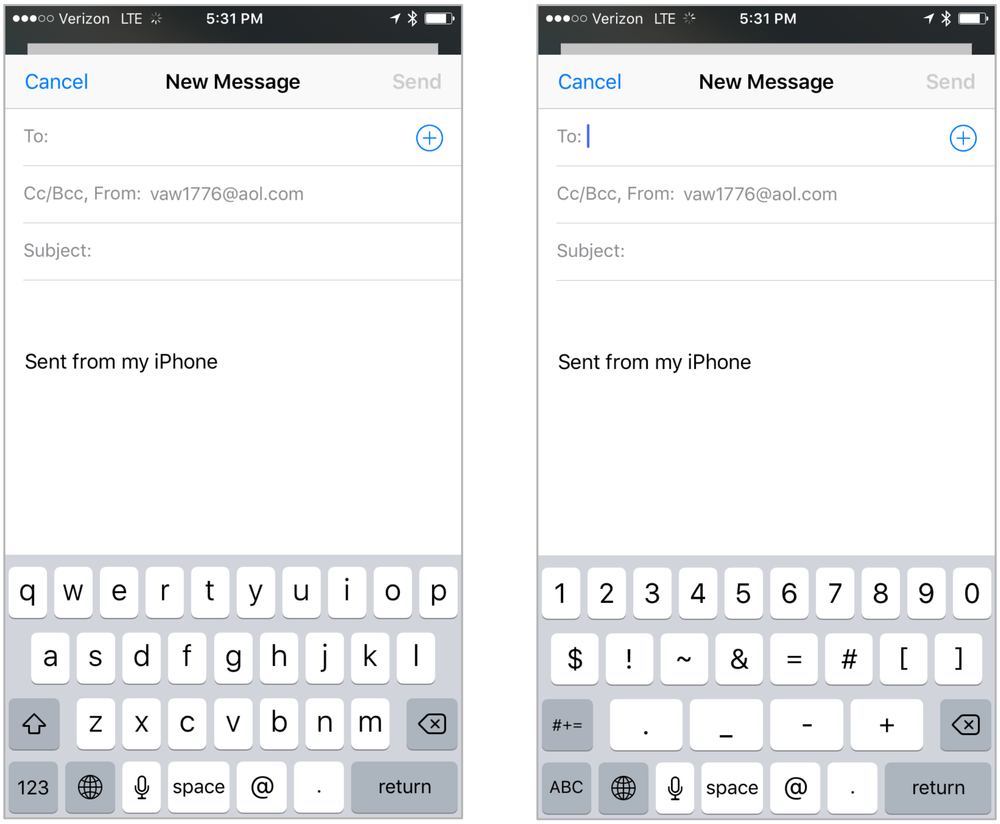

Figure 6. Mini-QWERTY soft keyboard on iPhone 6, UI view 1 and 2 (left to right).

Unlike physical keyboards, the mini-QWERTY keyboard UI changes, depending on whether the phone is being utilized in portrait or landscape mode, see Figure 7. Additionally, the keyboard only appears on-screen during text entry activities, disappearing once the task is complete (Allen, McFarlin, & Green, 2008).

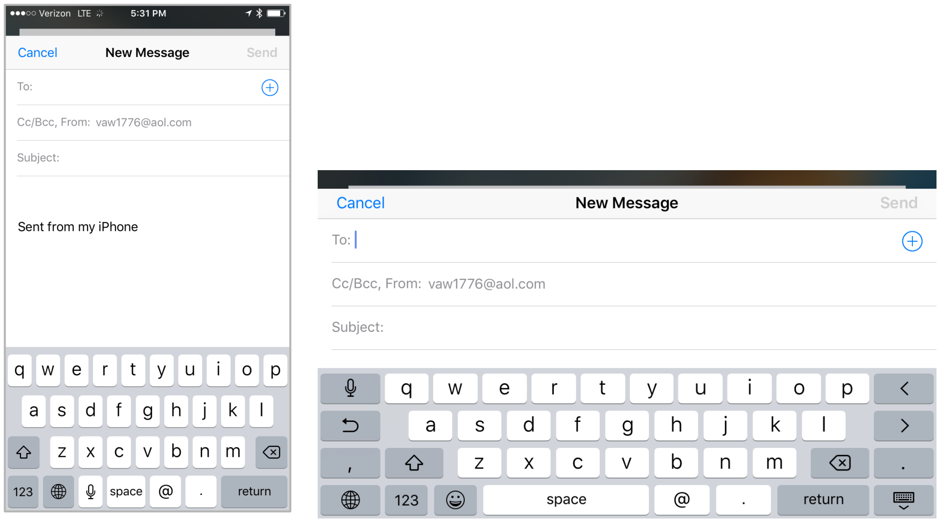

Figure 7. The portrait (left) and landscape (right) UI modes for the mini-QWERTY on the iPhone 6

Design and Usability Analysis of the mini-QWERTY Soft Keyboard

Though it shares a nearly identical QWERTY keyboard layout with the Sholes & Glidden typewriter, the iPhone 6 differs in many respects. Table 1 offers a high level view of these important differences. Chief among these are the devices' differing sizes, contexts of use, interaction styles, and constraints.

This paper will now examine specific aspects of the mini-QWERTY soft keyboard design, and the resulting usability issues.

Table 1

Chart comparing key aspects of the Sholes & Glidden typewriter to Apple's iPhone 6

	Sholes & Glidden Typewriter	iPhone 6
Product type	Hardware	Hardware & Software
Power type	Mechanically-powered, energy generated by user	Electrically-powered via rechargeable battery
Device size	Height: 18 inches Width: 20 inches Depth: 20.5 inches	<u>Device</u> Height: 5.44 inches (138.1 mm) Width: 2.64 inches (67.0 mm) Depth:0.27 inch (6.9 mm) Weight: 4.55 ounces (129 grams) <u>Display</u> 4.7 inches diagonally

		Stationary (e.g. seated, standing) and mobile usage (e.g. while walking, running)
Context of Use	Stationary, typically seated usage, primarily in business or home setting	Used in a wide variety of contexts (e.g. office; home; public settings (e.g. subway train); while traveling (in car, on foot), exercising, shopping)
Target user	Professional writers, typists and secretaries	Mass market; professional and non-professional users
Interaction style	Users manipulate physical keys	Users manipulate virtual, touchscreen keys
	Device typically operated via two hands; all fingers are engaged when using keyboard	Device typically held in one hand, and is operated either by the thumb of that same hand, or the index finger of the other hand
	Device supported by stationary surface (e.g. table, desk)	Device is generally supported in user's hands
	Wrists are free and able to adjust their movement and positioning to attain a comfortable typing posture	When held in hand(s), wrist(s) locked; limits finger and thumb mobility
	User able to "rest" fingers on home row ("ASDFGHJKL")	Users cannot "rest" fingers on touchscreen; touching a key will immediately activate it
	Keyboard generates clear, tactile feedback when keys activated	Touchscreen offers limited feedback (i.e. auditory and haptic) when keys activated; no physically detectable space between adjacent keys
Unique features/ constraints	Adjacent type bars prone to jamming when used in quick succession	Small size; both in terms of overall device and screen size
		Utilizes algorithms that autocorrect text based on what is most likely and generate the best n-alternatives to the words typed and make those selectable above the keyboard
Keyboard	Standard touch typing QWERTY keyboard	Mini-QWERTY soft keyboard
	Length: 13.25 inches Width: 5.75 inches	Height: 34mm (portrait mode); 25mm (landscape mode) Width: 58mm (portrait mode); 104mm

(landscape mode)

Data adapted from Apple, 2016; Baumann & Thomas, 2001; MacKenzie & Zhang, 1999; Bi, Smith, Zhai, 2012.

Size. In contrast to a standard QWERTY physical keyboard, which typically spans 700mm wide from tab to enter key, the iPhone 6 mini-QWERTY soft keyboard is significantly smaller, measuring 58 mm wide in portrait mode, the most commonly utilized orientation (Page, 2013). Whereas standard QWERTY keys are roughly 16mm wide, with key spacing (i.e. the center-to-center distance between adjacent keys) of 20mm, on the iPhone 6, these are only 5mm and 6mm respectively.

The small size and close proximity of keys on the mini-QWERTY keyboard, as opposed to the standard QWERTY keyboard, results in a number of usability issues, from slower typing speeds to higher error rates (Allen, McFarlin, & Green, 2008). This is particularly true when the mini-QWERTY keyboard is used on-the-go (Allen, McFarlin, & Green, 2008). Since users have comparatively large, blunt fingertips, they can occlude the keys or unintentionally activate neighboring keys (Dunlop & Levine, 2012; Toropainen & Ojala, 2008). In testing, adjacent keys such as “I” and “O” were frequently confused or inadvertently activated, leading to typos (e.g. if vs. of; in vs. on; hot vs. hit) (Dunlop & Levine, 2012).

Typing accurately on the mini-QWERTY keyboard, regardless of whether or not the user is in motion, demands high levels of concentration, and places greater cognitive load on the user as opposed to the standard QWERTY keyboard (Tan, Ng, & Oh, 2003). Typing on smaller keys has also been shown to lead to greater physical strain (e.g. neck, wrists, shoulders) (Shin and Zhu, 2011; Kim et al. 2013).

While the above issues are specific to mini-QWERTY, the soft keyboard also inherits weaknesses from its parent keyboard. For instance, like the standard QWERTY keyboard, mini-QWERTY fails to sufficiently take into account the varying finger and hand sizes of its user base

(Yoshitake, 1995). Instead, it offers only two, marginally different keyboard and key size options, accessible via portrait and landscape modes.

There are several known reasons for this problematic, miniaturized QWERTY keyboard. First and foremost, any text entry mechanism must allow for the input of a minimum of 36 characters (26 letters and 9 numerals) in order to communicate in the English language (Hsiao, Wu, & Chen, 2014). Since the keypad style of keyboard, in which multiple characters are contained on a single button, has been shown to perform worse than single character key keyboards, it is logical that the designers opted for the latter (Weiss, Kevil, & Martin, 2001)

By mimicking it, designers were also capitalizing on a user's prior knowledge, skill, and comfort level with the traditional QWERTY layout (Green et al., 2004). This reflects a longstanding practice of recycling UI elements, metaphors, and interaction behaviors to help users make the transition between one technology (e.g. the desktop computer) and the next (e.g. smartphone) (see Blackwell, 2006).

Additionally, designers were constrained by the small size and available screen space on the device, which limited the keyboard's size (Allen, McFarlin, & Green, 2008). Designers also opted to selectively display the keyboard during text-based activities, freeing up valuable screen space (Allen, McFarlin, & Green, 2008).

Interaction Style.

Touchscreen. Another defining characteristic of the mini-QWERTY soft keyboard is that it is operated via touchscreen. While the iPhone 6 touchscreen allows for largely intuitive, direct manipulation, as a mode of text entry, it presents several usability challenges.

For instance, unlike on the physical QWERTY keyboard, users cannot "feel" whether their fingers are located on or between keys (Paek et al., 2010). As a result, users must visually locate and click each character, then visually attend to the text output area of the device to confirm the text was outputted correctly (Paek et al., 2010). This high level of alternating, visual concentration increases the already significant cognitive load imposed by the small keys, mentioned in the prior section (Findlater &

Wobbrock, 2012). It also negatively impacts typing performance, in terms of speed and accuracy (Paek et al., 2010; Kwon, Lee, Chung, 2009). For instance, a user who is focusing on visually identifying the keys they are hitting, may neglect the text output field and miss errors (Paek et al., 2010). Not surprisingly, studies have shown that touchscreen keyboard users are less likely to notice errors than physical keyboard users (Brewster, Chohan, & Brown, 2007). The more errors missed, the most time-consuming the post-typing editing process, which is particularly challenging on an iPhone, requiring sensitive and specific touch interactions within the text output field (Paek et al., 2010).

Compounding these issues is the fact that the touchscreen only permits and recognizes a limited set of interactions. While the physical QWERTY keyboard allows for three key states—a finger can be off a key, resting on a key but not depressing it, and depressing a key, the mini-QWERTY soft keyboard only allows for the first and third states (Findlater & Wobbrock, 2012). This means that users cannot rest or anchor their fingers on the keyboard without triggering unintended key entries (Findlater & Wobbrock, 2012). This constraint, coupled with the lack of tactile feedback mentioned above, prevents users from engaging in the type of “blind keying” that makes typing on a standard QWERTY keyboard more efficient (Paek et al., 2010). The reason mini-QWERTY has been unable to accommodate this style of typing is due to the technical challenges associated with differentiating between nuanced tap patterns on a touchscreen (Findlater & Wobbrock, 2012).

While touchscreens clearly have challenges and limitations with regard to typing, designers had numerous motivations for utilizing them, such as their intuitive nature (Findlater & Wobbrock, 2012). Additionally, a touchscreen keyboard is software-based and, therefore, offers significant flexibility (Findlater & Wobbrock, 2012). It can be customized based on user preference, needs, behavior, and native language (Findlater & Wobbrock, 2012). The touchscreen keyboard also only appears when needed, saving valuable screen space, while also reducing the physical bulk of the device, one that is prized for being small and light (Allen, McFarlin, & Green, 2008).

Typing style. In contrast to the standard QWERTY keyboard, which was designed for stationary, two-handed use, mobile phones are frequently held in a user's hand while being operated, due to their small size, weight, and portability (Song et al., 2011). In fact, Park et al. (2008) found that users will generally avoid operating a smartphone with two hands unless one-handed interaction is very difficult.

When iPhone users hold the phone, they create a locked wrist position, which inhibits finger and thumb mobility (Baumann & Thomas, 2001). This is relevant as the most common means of operating an iPhone are by holding and operating it with the thumb of the same hand (74% of users), or by holding it in one hand and utilizing a single finger from the free hand as a stylus of sorts (Page, 2013; Song et al., 2011; Karson, 2006).

The mini-QWERTY soft keyboard fails to adequately account for this usage style and the physical/dexterity limitations of the thumb (e.g. less accurate and nimble than a finger; more prone to fatigue) (Baker et al., 2007; Olszewska et al., 2009; Colle & Hiszem, 2004). In order for a touch key to be activated, the "centroid" of the pressed area must fall within the recognition area of the target key (Park et al., 2008). However, it can be challenging for the user to calculate and activate the centroid when using a thumb.

Additionally, due to the anatomy of the hand, considerable thumb flexion and extension is required to successfully activate keys in certain areas of the keyboard (Trudeau et al., 2012). For right-handed users—the majority of the U.S. population—the thumb performs best when interacting with elements along the top right and bottom left of the screen (Trudeau et al., 2014). In contrast, typing performance is lowest, and perceived effort greatest, when users interact with the top left and bottom right of the screen (Trudeau et al., 2014). The reverse is true of left-handed users, while keys in the middle of the keyboard are generally more convenient to press for both user types (Park & Han, 2010; Trudeau et al., 2014).

Some of the keys located in these regions on the mini-QWERTY keyboard are very common (e.g. N, M, L, K, O, P) (Allen, McFarlin, & Green, 2008). For instance, Figure 8 shows an image of the mini-QWERTY keyboard on a first generation iPhone, and how the keys with the highest false alarm rates (i.e. mistyped) map against the most and least frequently used letters in the English language (Allen, McFarlin, and Green, 2008). Though the dimensions and key size of the mini-QWERTY keyboard on the iPhone 6 differ slightly from that of the first generation iPhone, the results are still informative and relevant to the current discussion.

This lack of thumb support is understandable, given that, on the standard QWERTY keyboard, the thumbs were only utilized to tap the space bar between words (Cooper, 1983).

Figure 8. iPhone keyboard showing letters with the highest false alarm rates (i.e. mistyped) and the most and least frequently used letters in English. Reprinted from Allen, McFarlin, & Green (2008).

Another usability issue related to the mini-QWERTY layout and iPhone typing patterns is that common consecutive letter pairs (e.g. th, gn, ck) are located on separate halves of the keyboard (Bi, Smith, Zhai, 2010). This worked well on the standard QWERTY keyboard, which was intended to be operated with two hands and allowed one hand to hit a key while the other positioned itself for the next key (Cooper, 1983). However, this layout works poorly on an iPhone, as its single thumb or finger operation necessitates frequent and inefficient back and forth movements across the keyboard (MacKenzie & Zhang, 1999).

Improvements and Alternatives to mini-QWERTY

When designers were developing the mini-QWERTY keyboard for the first smartphones, it is unlikely that they anticipated these new interaction behaviors (e.g. primary thumb operation), or the degree to which factors such as device and keyboard/key size, context of use, and various technical constraints (e.g. lack of tactile feedback from a touchscreen) would impact the user experience. Like countless designers before them, they likely believed that the standard QWERTY keyboard, which had adequately supported users on computers and typewriters, would be sufficient in a mobile context as well. This paper has shown this not to be the case.

Rather than continue to use the highly flawed mini-QWERTY keyboard, designers have an obligation to use the research to either improve mini-QWERTY's design, or create a better text entry option all together. For instance, designers could dynamically increase or decrease the size of keys depending upon their likelihood of being typed, place common characters in easier to access portions of the screen, and provide both right- and left-handed UI options. Designers could also leverage multimodal feedback (e.g. associating a different audible tonality with hitting the space bar vs. regular characters), as well as more sophisticated word prediction, completion, and correction algorithms (Himberg, 2003; Sears, 1991; MacKenzie & Tanaka-Ishii, 2007). While the latter have become increasingly common—and are, in fact, utilized by the mini-QWERTY keyboard on iPhone 6—these algorithms are generally flawed and their cognitive demands have been shown to negate any keystroke savings (Kiripolský, 2014; Koester & Levine, 2009).

Many alternative modes of mobile text entry have also been explored. These include handwriting and voice recognition, gesture/movement-based technologies (e.g. keyboard glove), facial recognition, and gaze-based text entry (Zhai, Hunger, & Smith, 2000; Goldstein et al., 1999; Romano et al., 2014; Spakov & Majaranta, 2008). Each of these offers different benefits and tradeoffs, depending on the user's preferences, needs, and context of use. Thoughtfully exploring all of these avenues, will likely lead to a comprehensive and nuanced approach to text input on mobile devices, moving forward.

Conclusion

Designing a mechanism for mobile text entry that is suitable for the mass consumer market is challenging. Users generally expect the mechanism to be as fast and easy to learn and use as their computer keyboard (Zhai & Kristensson, 2012). Most are accustomed to the QUERTY keyboard and are generally disinclined to invest time in learning a new interface, even if the long-term benefits outweigh the initial investment (Bi, Smith, & Zhai, 2010). This speaks to the perennial tension between efficiency and easy of adoption. Often interfaces can be easy to use by a novice, but fail to reward intermediate and advanced users (Zhai, 2008). Alternatively, an interface can have a high learning curve, but, through practice, enable the user to achieve high levels of efficiency (Zhai & Kristensson, 2012). The former is very much the case with the mini-QWERTY keyboard. While easy to learn, due to users' prior knowledge and touch typing skills, it presents substantive usability issues. These issues are largely due to the fact that the original QWERTY keyboard was not designed for modern mobile devices and users, and fails to take into account the mobile form factor, interaction patterns, and context of use, among other factors. Mini-QWERTY's small keys, close key proximity, lack of tactile feedback, and poor ergonomics, among other factors, detract from the user experience, and result in poor text entry speeds and accuracy.

Given the frequency and importance of text entry on mobile devices, substantial time and energy should be devoted to designing a more efficient, effective, and user-friendly mechanism to accomplish this. Some options include gesture-based keyboards as well as handwriting and voice recognition systems. In the end, the best approach will not only account for the smartphone's unique use case and interaction patterns, but will allow for customization based on the user's preferences, needs, context scenario, and behavior.

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