Examination of Text-Entry Methods for Tabletop Displays

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Abstract

Although text entry is a vital part of day-to-day computing familiar to most people, not much research has been done to enable text entry on large interactive tables. One might assume that a good approach would be to choose an existing technique known to be fast, ergonomic, and currently preferred by the general population, but there are many additional factors to consider in this specific domain. We consider a variety of existing text-entry methods and examine their viability for use on tabletop displays. We discuss these techniques not only in terms of their general characteristics, performance, and adoption, but introduce other evaluative criteria, including: environmental factors unique to large digital tables and the support for multi-user simultaneous interaction. Based on our analysis we illustrate by example how to choose appropriate text-entry methods for tabletop applications with differing requirements, whether by selection from existing methods, or through a combination of desirable elements from a variety of methods. Our criteria can also be used as heuristics during the iterative design of a completely new text-entry technique.

1. Introduction

Text entry is one of the most frequent actions we undertake when working on desktop computers. Entering text is necessary for activities that require elaborate text compositions such as coding programs, authoring articles, or writing emails, as well as in situations that demand taking notes, typing in commands, or annotating content.

Text-entry methods are equally important for digital tables. Although a large variety of tabletop applications have been developed in the last decade [4, 5, 31, 32, 36], not much attention has been paid to the development of text-entry methods for tabletop displays. However, the unique characteristics and affordances of large digital tables, such as the support for multiple people and the large horizontal workspace, demand unique text-entry methods that differ from traditional physical keyboards. Enabling tabletop text entry in a way that suits the overall characteristics and affordances of large digital tables will make them more viable for everyday work and entertainment applications.

In this paper, we analyze existing text-entry methods that have been developed for desktop computers, touch sensitive tablet PCs, mobile phones, or personal digital assistants (PDAs) and examine their potential for use on tabletop displays. With this analysis we hope to seed a research agenda within the tabletop community to develop and evaluate novel text-entry methods for tabletop displays. While the research effort for tables has thus far typically focused on information manipulation and display, our reliance on the ability to enter text with most other computing technologies suggests that this research direction should be at least equally important. Our research is intended to help designers and developers of tabletop systems to invent or choose an appropriate text-entry method depending on the tabletop application's purpose and character.

We first define our evaluative criteria for text entry on digital tables. We then describe and discuss different categories of existing text-entry methods. After this we discuss the potential of the examined methods for a variety of tabletop applications and provide guidelines for the development and evaluation of future tabletop text-entry methods.

2. Evaluative Criteria

Our examination of text-entry methods is based on criteria specifically important in tabletop display environments. These criteria include visual appearance, performance, environmental factors, and simultaneous interaction.

2.1. Visual Appearance

For text-entry methods that have a visual representation of characters, the visual appearance is defined by the overall *character arrangement* (shape) and the *character layout*.

The arrangement of characters determines the overall shape of the typing device (rectangular, circular, star-shaped, etc.), while the character layout determines where specific character keys are located within the general arrangement (Q next to W, W next to E, etc.) [20]. The most common character arrangement in western culture follows a rectangular shape with a QWERTY character layout [19]. As we will later describe, the character arrangement and layout can influence the performance of a text-entry method.

While most text-entry methods have a visual appearance, for some (e. g. speech recognition and handwriting), these criteria do not apply.

2.2. Performance

The performance of text-entry methods is defined by two factors: *efficiency* and *ease of learning*. An ideal text-entry method would combine these factors to their mutual benefit.

2.2.1. Efficiency. Efficiency is most often defined as the effective text-entry speed that a person can reach using a certain text-entry method [40]. This speed is usually measured in words per minute (wpm). For text-entry methods with a visual representation the efficiency is a function of the visual search time to find a certain character and movement time from one character to the next [18, 19]. The character layout, therefore, has an important impact on the efficiency since by minimizing distances between consecutive characters (digraphs) the movement time can be minimized as well [7, 17, 18, 19]. However, typing speed depends on several other variables that are hard to control in empirical studies. For example, the amount of training time on a given method or the level of familiarity with related typing methods can bias the outcome of typing speed measurements. In addition, to be meaningful, efficiency measures must be viewed alongside data about typing accuracy.

Often, costly long-term studies are required to make confident statements about the speed of a certain text-entry technique [40]. In order to save these costs, several predictive models have been developed, mostly based on Fitts' law, that can estimate the performance of a text-entry method [8, 18, 39]. However, the accuracy and validity of such predictive models is problematic because certain parameters within Fitts' law need to be estimated.

Another factor that determines the efficiency of a text-entry method is the visual and cognitive attention it requires [40]. The lower the attention demand, the more efficient the text-entry method [40]. As we will describe later, some methods allow for blind typing after training while other methods always require some visual attention.

2.2.2. Ease of Learning. The success of a text-entry method not only depends on its efficiency but also on its learnability. If it takes a long time to learn a method people will not adopt it. A new text-entry method will first have a lower performance than an established method [19, 40], but potentially can, after training, exceed the existing one. This "crossover point" is an important indicator for ease of learning [19].

Efficiency and ease of learning often conflict with each other [35]. Very few text-entry methods have a high initial performance and require little learning to achieve a high general performance. Therefore, it can be crucial to rate the importance of efficiency and learnability depending on the application area the text-entry method is intended for.

2.3. Environmental Factors

While text-entry methods have been studied extensively for the domain of desktop computers [6, 7, 22, 38] or small portable devices such as cell phones or PDAs [2, 11, 15, 17, 20, 23, 34] not much research has been done for the domain of tabletop displays. For tabletop text-entry methods the unique characteristics and affordances of tabletop displays play an important role. We describe some of the table-specific factors relevant for text entry, such as size, orientation, and the support of direct-touch interaction.

2.3.1. Space Requirements. Large digital tables have a large virtual workspace. This allows for tasks that involve large amounts of information and co-located collaboration between multiple people [26, 24]. The workspace size needs to be considered for the design of text-entry methods. Two different approaches are possible: external text-entry methods involving physical devices separate from the workspace and on-screen methods where the interaction space and the display space are superimposed. Both approaches have been developed for small displays, but the affordances of large digital workspaces are quite different.

Tabletop displays have more screen real estate available, and so an on-screen text-entry method can use more space and can involve the use of multiple fingers or two-handed interaction. However, an on-screen method that is too large may clutter the display and interfere with the space left available for information items. External methods do not interfere directly with the display space, but can require people to be slightly more removed from the display when entering text. This separation can make it difficult to maintain an overview of the entire space and an awareness of others in the environment.

With regard to space requirements of a text-entry method an important criterion to consider is its ability to be collapsed (*collapsibility*). Collapsing the keyboard can be a way of dealing with the added external or on-screen space required by a text-entry method. Collapsing can be done for physical keyboards by, e. g., providing a drawer to hide it or using a foldable keyboard. For on-screen keyboards, the visual keyboard representation can be collapsed at the request of the person using it, or automatically after a time delay. Typically, collapsing of physical devices requires more time and effort than collapsing a virtual on-screen device.

2.3.2. Rotatability. The horizontal orientation of tabletop displays can also influence text entry. Text input is orientation-dependent on tables, since the display can be approached from different directions. It may be desirable to provide a mechanism (if one does not naturally exist) to alter the orientation required for entering text. This rotation can be done for physical devices by rotating the device itself. For on-screen methods, rotation must be supported programmatically. However, we do not yet know how this orientation influences performance. Previous studies have investigated the impact of the display angle on touch-tapping as an input method for text entry [1, 27] but more refined studies have to be conducted for tabletop displays in particular.

2.3.3. Direct-Touch Interaction. Most tabletop systems support direct-touch interaction using styli or hands [5, 21, 30]. Direct-touch is especially beneficial on tabletop displays because it provides awareness cues to others at the table. Ideally, a text-entry method would interfere as minimally as possible with these cues, allowing fluid transitions between text-entry and direct-touch interaction. Some existing methods could be disruptive in a tabletop environment, since they require people to switch input methods or devices, preventing a continuous awareness of their actions and the effects they have on the environment.

2.3.4. Mobility. Digital tables afford walking around the display to obtain an alternative viewpoint, e. g., when looking at virtual maps. It may also be desirable to enter text at any of these possible viewpoints. Ideally, a text-entry method would support entering text from any location, without interfering with a person's physical ability to move around the table. For example, a wired physical keyboard may not be appropriate, since the wire would prevent circling the table several times. Carrying a physical device may also introduce fatigue.

2.4. Simultaneous Interaction

Studies have found that tabletop displays provide a space where many people can work closely together [24]. In order to support smooth and fluid co-located collaboration, tabletop displays need to support simultaneous multi-person interaction [26]. This need also must be taken into account when developing text-entry methods on tabletop displays. To support simultaneous interaction, the following criteria are important to consider: *shareability* and *duplicability*.

For applications that require very few and infrequent annotations, it might be suitable to only provide a single text-entry device that can be easily shared between multiple people. For other applications, every person interacting with the digital table may need a text-entry device. Methods that support the fast duplication of text-entry devices might be one solution for such applications.

In the following section, we examine existing text-entry methods based on the described criteria: their general characteristics, their performance, how they can be integrated in a tabletop environment considering its unique factors, and how they can support simultaneous multi-person interaction. Table 1 shows an overview of the methods we are examining in terms of the tabletop-related criteria described above.

3. Investigating Existing Text-Entry Methods

Existing text-entry methods generally fall into two categories: *external methods* require an external physical device and *on-screen methods* are controlled in the same display space as the information being displayed (see Table 1).

3.1. External Text-Entry Methods

External text-entry methods include physical keyboards that traditionally belong to a common desktop computer environment, mobile physical keyboards that can be found on cell phones or PDAs, and speech recognition techniques.

3.1.1. Physical Keyboards. The majority of desktop computers provide physical keyboards to enable text entry. A physical keyboard benefits from tactile feedback, improving the touch-typing performance. Physical keyboards can vary slightly in shape and character layout, but they are mostly based on the QWERTY layout described by Sholes in 1867 [38, 40]. While this layout was initially designed to avoid jamming on mechanical typewriters, its design supports alternating between both hands while typing.

Due to the visual representation of characters, novice users can apply the "hunt-and-peck" strategy using one or two fingers. With training, however, people can learn two-handed typing using ten fingers. Experts can even type without paying any visual attention to the physical keyboard. According to predictive models, the expert typing speed on a physical QWERTY keyboard is 56 wpm [22]. Various attempts to replace the QWERTY layout on physical keyboards (e. g. the Dvorak keyboard [7] or alphabetical layouts [22]) have remained unsuccessful. Due to the large majority of people familiar with the QWERTY layout this trend is not very likely to change.

As an external and somewhat large physical device, a physical keyboard does not lend itself well to a digital tabletop environment. Switching back and forth between touch-typing on an external keyboard and direct-touch interaction within the virtual workspace can be disruptive. Also, a physical keyboard can be hard to move around, rotate, or share between multiple people. Multiple keyboards can be provided for multiple people interacting on a tabletop display but the number of keyboards is limited due to their size and the available space. Another drawback of a physical keyboard is that it always requires a physical surface on which it can be placed. One could imagine drawers to store physical keyboards, installed around a tabletop display. However, this is difficult to integrate into current tabletop setups, especially when the display is projected from below. Storing and retrieving a physical keyboard would be clumsy, in particular for tabletop tasks that require quick annotations from

Table 1. Environmental criteria applied to different existing text-entry methods.

	Physical Keyboards	Mobile Keyboards	Speech Recognition	Handwriting	Gestural Alphabets	Stylus Keyboards
Space Requirements	high	low	none	none	none	variable
Collapsibility	possible	possible	not applicable	not applicable	not applicable	supported
Rotatability	limited support	possible	not applicable	not applicable	not applicable	supported
Direct-Touch Interaction	limited support	supported	supported	supported	supported	supported
Mobility	limited support	supported	supported	supported	supported	supported
Shareability	limited support	supported	supported	supported	supported	supported
Duplicability	not possible	not possible	not applicable	not applicable	not applicable	supported
Simult. Text Entry	limited (space)	supported	limited	supported	supported	supported

time to time. Permanent keyboard ledges would also create a barrier between people and the interaction space.

3.1.2. Mobile Physical Keyboards. We define mobile physical keyboards as mobile devices that have some sort of physical text-entry method. Examples for this are mobile phones or PDAs that use physical buttons for text entry. Similar to traditional ones, small physical keyboards allow touch-typing using fingers, since tactile feedback is provided. However, on small mobile devices people usually type with one finger, either while holding the device in the same hand they are typing with or in their other hand [29]. The visual appearance of mobile physical keyboards varies from device to device. Small QWERTY keyboards can be found on some PDAs. Some mobile devices have miniature alphabetical keyboards, often used with two thumbs. The most common typing interface on mobile phones is based on a physical 12-key pad [29]. Studies show that text can be entered using the T9 extension for text entry [10] at approximately 45.7 wpm for expert users [29].

In digital tabletop environments, mobile physical keyboards may be a suitable text-entry method. People can hold the mobile typing device in one hand while interacting with the tabletop workspace using the other hand. Physical keyboards with the size of a mobile phone can easily be shared between people, placed in a pocket or on the physical edge of the digital table without taking up much space. Many people are also familiar with the T9 input method from sending SMS messages [18]. However, since SMS messages are typically short, it still needs to be determined if the T9 method is suitable for typing larger amounts of text.

3.1.3. Speech Recognition. An alternative to manual text-entry is the use of automatic speech recognition. We include this method in the category of external methods, since it usually requires people to wear microphones. Speech recognition as a text-entry method is compelling because it does not require any learning on the part of the user. The quality of speech recognition is not dependent people's skills but on the technology translating human speech into machine-readable text. Although technology has improved over the recent years, studies have found that speech recognition is significantly slower than keyboard typing [13]. Studies have also revealed that people have more difficulties composing text by talking out loud than by typing [40].

Speech recognition as a text-entry method on tabletop displays has the advantage that people can move around and have both hands free to directly interact within the tabletop workspace. However, when multiple people are collaborating around a digital table they often divide up a task in order to work on different aspects individually [25]. With speech recognition, several people might need to talk out loud at the same time in order to enter text into the system. Collaborators at a tabletop display are likely to be within earshot, so such simultaneous talking is likely to be highly disruptive.

3.2. On-Screen Methods

On-screen text-entry methods are controlled directly within the display space (typically through touch). Within the group of on-screen methods, we distinguish between handwriting, gestural alphabets, and stylus keyboards.

3.2.1. Handwriting. Text-entry methods that support natural handwriting by moving a stylus or finger continuously over the touch-sensitive workspace are similar to speech recognition in their intuitiveness. Instead of having to learn a new technique, people can just apply familiar writing skills. In recent years handwriting recognition algorithms have been improved to closely match people's expectations [14]. The performance bottleneck of handwriting, however, is not due to computational but human limitations. With approximately 15 wpm, the speed of human hand printing is quite low compared to the performance of other text-entry methods [15]. Thus, handwriting is not a suitable entry method for long text passages but might be sufficient for short annotations.

Handwriting as a text-entry method fulfills and complements the unique characteristics and affordances of tabletop displays. It supports the mobility of people working around a tabletop display, it only requires hands or a stylus, and it complements existing direct-touch interaction methods for manipulating virtual artifacts. It also supports interaction by multiple people without leading to interferences, as with speech recognition. Handwriting is, thus, a highly lightweight text-entry method for tabletop displays. However, as described above the performance limitations are a drawback that make it unsuitable for certain tabletop applications. In addition, the relatively low input resolution on current large digital tables [12] can negatively impact the accuracy and speed of handwriting recognition. Also, current input solutions on tabletop displays can cause problems when resting the hand on the tabletop surface while writing because the hand could block cameras.

3.2.2. Gestural Alphabets. Gestural alphabets were developed to increase the speed and the accuracy of handwriting on touch-sensitive surfaces [9]. Instead of allowing for individual handwriting, they provide a gestural representation for each character. Different gestural alphabets have been developed such as Unistrokes [9] and Graffiti [3]. Most of the effort in developing these alphabets has been put into making the representations of characters easy to learn and easy to computationally distinguish from other characters [9]. Unistrokes' performance was found to be 34 wpm [9, 15]. Although much faster than handwriting, this speed comes at the cost of learnability. Unistrokes was also found to be harder to learn than Graffiti, which may explain its low adoption rate [16].

Gestural alphabets were developed for small mobile devices that have touch-sensitive displays. With regard to environmental factors unique for tabletop displays, they have similar advantages as handwriting. Because gestural alphabets use fluid gestures with a stylus or finger, they are compatible with other direct-touch interaction techniques. As with handwriting recognition, no visual representation is required, thus issues such as collapsibility, rotatability, mobility, shareability, and duplicability do not apply. However, using gestural alphabets on a large display may be problematic due to the lack of physical boundaries present on small mobile devices. This lack of constraints may lead to "sloppiness" when writing, which has been shown to result in more recognition errors [9]. Introducing small physical frames as suggested by Wobbrock et al. [37] may prevent such errors, but requires an additional physical device (a plastic frame) and might be hard to install on a large display.

3.2.3. Stylus Keyboards. In contrast to handwriting and gestural alphabets, stylus keyboards have a visual representation within the virtual workspace. This visual representation can help to guide the novice user. A keyboard in the virtual workspace also has the advantage that it can be flexibly tailored toward the application it is used for or the environment it is installed in. For digital tables this means that a stylus keyboard can be easily developed to be collapsible, rotatable, mobile, shareable, and dublicatable. Furthermore, direct-touch interaction stylus keyboards are compatible with other touch interactions for manipulating virtual artifacts on a table. Therefore, one might conclude that stylus keyboards have the most potential on tabletop displays. However, the performance of stylus keyboards is highly design dependent. Another drawback is that the visual attention required for stylus keyboards is relatively high compared to physical keyboards or gestural alphabets.

Among stylus keyboards we distinguish between soft keyboards that are direct visual mappings of physical keyboards with some variations and gesture-based keyboards that differ in shape to support continuous gesture strokes.

Soft Keyboards. The input method for soft keyboards is touch-tapping, directly mapped from touch-typing on physical keyboards. Although soft keyboards can in theory support text entry using multiple fingers or hands, most existing systems are for single-finger or stylus input because they were designed for mobile devices. Soft keyboards typically have a rectangular or squared shape [19].

The character layout of a soft keyboard directly influences its performance. Many alternatives for the QWERTY layout have been developed for soft keyboards including alphabetical layouts, optimized arrangements based on frequently used letters and digraphs or arrangements based on physical models [17, 19, 39]. Prediction models for soft keyboards estimate an expert typing speed between approximately 43.3 wpm (for the QWERTY layout) and 55.9 wpm (for the FITALY layout [33]) and a novice typing speed of around 9 wpm (QWERTY, FITALY, alphabetical order, and others) [19]. These values differ largely based on the prediction model used and often do not conform with empirical studies [19, 39]. Also the optimal size of character keys has been studied for soft keyboards, partly with contradictory results. Sears et al. [28] state that the smaller the soft keyboard the more the typing speed decreases while MacKenzie et al. [18] found that the error rate on smaller soft keyboards increases but that there is no significant difference in text-entry speed between small and large soft keyboards. Since all these studies have been conducted on small mobile devices using one-handed input, they must still be tested in a tabletop setting to know if their findings generalize. In particular, we expect these values to vary greatly when people are allowed to use two hands.

Gesture-based Keyboards. In contrast to soft keyboards, gesture-based keyboards allow for continuous gestures to connect different visually presented letters without lifting the stylus or finger from the tabletop surface while entering a word. This continuity of gestures can improve text-entry speed [20, 23, 35]. Several gesture-based keyboards have been developed [11, 20, 23, 34, 35] following different approaches. Some systems show all characters, e. g. in a circular layout [20, 23]. One of the problems with this approach is that the space for each character decreases which leads to an either very large keyboard or to very small character keys that are, as a consequence, hard to select. In order to save character space, some systems try to divide up characters in groups and show only the parts of the character set that are needed [11, 34]. Other systems make use of predictive language models to visually emphasize characters likely to follow the previous one and minimize the rest in order to save space [35].

Gesture-based keyboards, in particular those with hidden characters and predictive language models, require some learning. Since touch-tapping seems to be a natural mapping from touch-typing, and because our everyday workstations still mostly rely on the point-and-click metaphor, a gesture-based keyboard will first appear unfamiliar to most people. This lack of familiarity needs to be considered for certain applications that require immediate efficiency.

4. Discussion

The above survey of existing text-entry methods and their potential usage on tabletop displays shows that there is no *perfect* method that can be applied without drawbacks. Although according to our analysis physical keyboards seem to be fairly unsuitable as a text-entry method for large tabletop displays, they might be appropriate for applications on small tables where a limited number of people interact and rarely change their working positions. In this case, the performance benefits of physical keyboards may outweigh the environmental factors and the need to support simultaneous interaction. In a multi-person co-located environment, text entry via speech recognition can be awkward when simultaneous text entry is desired (since people would need to speak over one another). However, in situations where text would typically not be entered in parallel, its intuitiveness and the lack of space constraints may be desirable. For tabletop applications that only require small annotations from time to time, handwriting or mobile text-entry devices might be suitable, despite the performance costs.

Our survey shows different strengths and weaknesses of existing text-entry methods in terms of their usage on tabletop displays. The character of the tabletop application and the target user group are important factors to consider when choosing an appropriate text-entry method or developing a new one. Therefore, standard user-centred design guidelines can be customized, focusing on questions such as:

- *What* is the purpose of the tabletop application? Is it a work application where efficiency is highly important or a walk-up interface where intuitive usage and visual adjustibality become more important than efficiency? Does it require small annotations or the input of large amounts of text?
- *Who* are the people that are going to interact with the tabletop display? Are they frequent keyboard users, novices, elderly people, children, etc.?
- *How* are people going to interact with each other on the digital table? Does the task require mobility or simultaneous text entry?
- *How often* will people interact with the system? Will it be worthwhile for them to learn a new text-entry method or will their use of the table be too infrequent?

Although our examination based on our evaluative criteria does not give clear answers, it shows tendencies and provides guidelines for evaluating existing and new text-entry methods for tabletop displays. The guiding questions above can help to weigh the criteria depending on the application area and targeted user group. This weighting can provide important design constraints, informing innovative text-entry methods specifically tailored toward tabletop displays.

4.1. Application Scenarios

The following two scenarios give an example of how some of the examined text-entry methods can be applied for certain tabletop applications. We describe one workplace scenario and one public walk-up-and-use scenario.

4.1.1. Work Scenario. A tabletop work scenario could involve a team of people working on a museum's catalogue. This task involves digital information in the form of text passages and photos spread out on a tabletop display. Often, such teams will divide up the work. For example, the graphics designer in the team might start to arrange the photos within a page layout while the content managers work on the creation of textual content that is still missing, or edit text passages to fit better into the design. Working together on the same large display is beneficial because upcoming questions can be quickly clarified and changes can be done immediately with the whole team involved. For the graphics designer's task, short annotation within the page layout is required. Certain parts of the layout may need short comments or marks for later refinement. For this task, *handwriting* is a suitable text-entry method, since it allows a person to quickly annotate while moving around freely to look at the page layout from different perspectives. Since the annotations can be done by hand or with a stylus, it is easy to switch back and forth between annotating and manipulating content in the tabletop workspace. For the content managers who create additional textual content, a *physical keyboard* that is installed in the tabletop system is a good way to enter text. For them, it is most important to be able to efficiently enter large amounts of text into the system. Mobility or shareability of the text-entry system is not important. For editing text passages already embedded in the page layout on the tabletop display, a *gesture-based keyboard* or *gestural alphabet* might be most appropriate. They are more efficient and accurate than handwriting but the text passages can still be edited in place. Both techniques also support a high amount of mobility and shareability.

4.1.2. Walk-up-and-use Scenario. For a company that designs and develops public tabletop installations for museums or trade shows, intuitiveness and immersiveness of the tabletop interface have highest priority. Their clients expect tabletop systems that look visually appealing and that are tailored toward the theme of the particular exhibition. The tabletop interface needs to invite people to interact with it. In this scenario, text-entry functionality can be provided through *soft keyboards*. Because they exist in the virtual space, soft keyboards can be visually tailored toward a certain look-and-feel that matches the overall tabletop interface. A QWERTY character layout and touch-tapping input method can be used to capitalize on the familiarity of most people with QWERTY keyboards. Additionally, language models that highlight characters with a high probability to follow the previously typed character can be applied. This helps those not familiar with QWERTY keyboards to enter text. Mechanisms to collapse soft keyboards can save work space. In general, soft keyboards can be designed to be rotatable and translatable across the tabletop workspace making them easy to share between multiple people. Although soft keyboards using a QWERTY layout are not the most efficient text-entry method, they are highly suitable for supporting an intuitive and immersive multi-user experience. In contrast to our work scenario, it is acceptable to sacrifice efficiency for our other evaluative criteria. Namely, the visual appearance should be aesthetically pleasing, the method should not interfere with the space required for the main attraction, the entry method should be collapsible, rotatable, minimally interfere with direct-touch interaction, allow people to remain mobile and support many people using the display simultaneously. An appropriately designed soft keyboard can achieve a balance between these criteria.

4.2. Evaluation of Text Entry Methods

Our examination of existing text-entry methods for their potential use on tabletop displays is the first step toward enabling text entry on tables. As a next step, both their efficiency and their suitability for specific tabletop display environments need to be empirically evaluated. For efficiency testing, predictive models should be developed that also take two-handed typing into account. These models are also important for developing new text-entry methods for tabletop displays since they are less costly than empirical studies. Additionally, observational user studies can provide insights into people's subjective preferences regarding text-entry methods for tabletop displays. People's satisfaction is crucial for the adoption of a text-entry method.

Long-term studies need to be conducted that provide insights into the learning curves of text-entry methods. Although some learning-curve studies have been reported for small mobile devices, their results are not directly applicable for tabletop displays due to the different environmental factors, nor are they directly comparable to each other because they used different study parameters [40].

Since the tabletop research community is just starting to investigate text-entry methods, we should learn from the problems encountered studying text-entry methods for mobile devices [40]. We as a community need to come up with consistent methods to empirically study text-entry methods on tabletop displays for gaining comparable results throughout different research laboratories.

In-depth studies of text-entry methods on tabletop displays can lead to the development of new innovative methods specifically tailored toward tabletop displays.

5. Conclusion

In this paper we have examined existing text-entry methods for their potential use on tabletop displays. Our examination is based on a collection of evaluative criteria that directly follow from the environmental characteristics of tabletop displays. We analyzed text-entry methods for their space requirements, collapsibility, rotatability, their compatibility with other direct-touch interaction techniques, and their support of mobility, shareability, duplicability, and simultaneous multi-person interaction.

Although our examination cannot provide a clear answer about which particular text-entry method is the best for tabletop displays, it reveals tendencies that help to choose text-entry methods depending on the tabletop application and targeted user group. While not much research has been done so far regarding text-entry methods on tabletop displays, our analysis provides first insights into this important topic. Text entry is an essential activity for all sorts of applications and more research needs to be done regarding how to support this activity on tabletop displays. The evaluative criteria we applied for our examination can be understood as guidelines for the empirical evaluation of existing text-entry methods on tabletop displays and the development of new techniques specifically tailored toward large digital tables.

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