C-QWERTY: a text entry method for circular smartwatches

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Abstract

We present a study aimed at comparing different circular layouts for entering text on smartwatches. In particular, we measured the extent through which the use of a QWERTY layout increases user performance in the earliest sessions of use. To this aim, we designed C-QWERTY, a soft keyboard designed for circular smartwatches in which the keys are arranged along the edge of the screen in a circular layout. In order to make the keyboard more familiar to users, the order of the keys is similar to the one of traditional rectangular QWERTY keyboards. The method supports two interaction modes: tapping and gesture, in which a whole word can be written with a single gesture. As an evaluation, we compared the C-QWERTY layout with Cirrin, another circular layout in witch the order of the characters has been optimized to minimize the distance between successive keys during writing. The experimental results showed that the C-QWERTY, with a text entry speeds of 9.1 wpm and 7.7 wpm (tapping and gesture mode, respectively), outperformed the Cirrin layout with entry speeds of 6.6 wpm and 5.5 wpm. The increase in text entry speed due to the use of the QWERTY layout was 38 percent.

Keywords: *Text entry; Smartwatch; Gestures; Touchscreen.*

1. Introduction

Smartwatches have recently emerged as new wearable computing devices, but the small size of the screen may however, in some cases, make it difficult to interact with them. One challenge in this area is text entry, and researchers are introducing new text entry techniques for smartwatches in order to increase efficiency [1, 5].

Interestingly, many of them are adopting the QWERTY layout. This is probably done to exploit users' previous knowledge, as most of them use the QWERTY keyboard habitually, and to avoid that users have to invest time to learn a new layout. However, when the full QWERTY layout is fitted on a smartwatch screen the keys become very small. To solve this problem various techniques have been developed, as described in the next section.

In any case, a rectangular layout is more suitable for screens of the same type, while in a circular display, as in smartwatches, it can waste a lot of screen space. In this case a circular layout could allow a more efficient use of the screen space, but it is obviously very different from the QWERTY layout already known by users.

The purpose of this paper is to present a study on circular layouts for text entry on smartwatches. For this purpose we have decided to measure how much a QWERTY-like circular layout can improve user performance, especially at the first sessions of use. For this reason we have designed C-QWERTY, a soft keyboard for circular smartwatches in which the keys are arranged along the edge of the screen in a circular layout, and the keys have similar order of the ones of a traditional rectangular QWERTY keyboards. C-QWERTY also supports two types of interaction, tapping and gesture, in which a whole word can be written with a single gesture. To evaluate the performance of the C-QWERTY layout we therefore decided to compare it, through a user study, with another circular layout called Cirrin, in which the order of the characters has been optimized to minimize the distance between successive keys during writing.

The paper is organized follows: Section 2 describes previous work on text entry on smartwatches and on circular layouts; Section 3 describes our layout and text entry method, Section 4 shows its experimental evaluation and

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Section 5 the evaluation results. Finally, Sections 6 concludes the paper with a discussion on future work.

2. Related Work

As in the case of smartphones and tablets [13, 25, 19, 7, 6], numerous text entry techniques have been proposed to facilitate text entry on smartwatches. To solve the problem caused by the smartwatches small screens, a common approach is to introduce a further interaction step on soft keyboards. In SplitBoard [12] only a part of the keyboard is shown at any given time and a flick is used to change the displayed part. In ZoomBoard [18], instead, a zooming step is used to increase key sizes. In ZShift [14] a callout is used to show a zoomed copy of the screen under the user's finger. Such interaction steps, however, increase the time required to select each key. Another approach to the problem is to use gestures to select keys. SwipeBoard [4] is a eyes-free text entry method in which two swipes are used to enter each character. DualKey [10] uses keys with two letters and tapping gestures with two different fingers to choose between them.

Other techniques instead use a word-based (e.g. WatchWriter [9]) or a sentence-based (e.g. VelociTap [24]) text entry approach.

It can be noted that all of above mentioned techniques are based on rectangular (QWERTY) keyboards. A rectangular layout, however, is naturally more suitable for screens of the same type. On a circular screen, instead, this layout can cause a waste of screen space. In this case a circular layout could allow a more efficient use of the screen space. In fact, in addition to the common rectangular layouts, there are also some keyboards with circular layouts, that are used to exploit such layout advantages in scenarios such as rotational interfaces [20] or personal area on the tabletop [2].

One of the first circular layout to be proposed is Cirrin, a text entry method for pen input devices based on a soft keyboard proposed by Mankoff and Abowd in 1998 [17]. Here, the keys are arranged in a circle, as shown in Figure 1, and the layout of the letters in the circle is such as to minimize the average distance traveled by the pen to write a word. This is because the user, to insert a word, simply draws a path, starting from the inside of the circle, that crosses the circumference in points corresponding to the characters of the desired word, in the right order. A space character is automatically inserted when the pen is raised. Cirrin has shown to have the potential to be faster than the classic QWERTY virtual keyboards and is particularly suitable for pen based devices.

Some techniques use characters in alphabetical order. Shoemaker et al. [21] proposed a circular keyboard for entering text on large wall displays. The selection is performed by moving the pointer over the desired character and

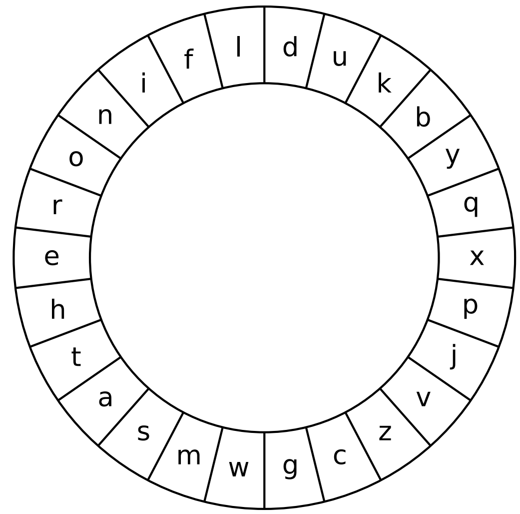

Figure 1. Cirrin Layout.

by pressing a button to enter it. BubbleCircle [11] uses a ring arrangement of alphabetic characters on a tabletop display and magnifies the next most probable characters based on the user's input. TUP [20] is a text entry method for touch sensitive wheels. The characters are positioned on fixed positions on the wheel and the user presses a select key to enter the highlighted character.

3. C-QWERTY

Our layout, C-QWERTY, is a keyboard layout for circular smartwatches in which the alphanumeric keys are arranged along the edge of the screen in a circular layout. In order to make the keyboard more familiar to users, the keys are arranged in a similar way to that of traditional QWERTY keyboards, as shown in Figure 2.

In particular the keys corresponding to the first row of the QWERTY keyboard have been positioned at the top of the screen (from right to left: q, w, e, r, t, y, u, i, o, p), while those corresponding to the third keyboard row have been positioned at the bottom of the screen (from right to the left: z, x, c, v, b, n, m). In the remaining space on the sides, in the central part of the screen, the keys corresponding to the second keyboard row have been positioned partly on the left (from top to bottom: a, s, d, f) and partly on the right (from top to bottom: g, h, j, k, l).

In order to make the best use of the available screen space, our C-QWERTY soft keyboard implementation has on the center of the screen a text field that shows the transcribed text. Above this field there are the space and backspace keys, while below it there are up to 4 suggestion words in order to complete the current written word. This functionality uses a 20K words dictionary.

Figure 2. C-QWERTY Layout.

The keyboard has two interaction modes for entering text: tapping and gesture. In the first mode, by tapping on a key it is possible to enter the corresponding character. In gesture mode, in addition to tapping, it is also possible to enter an entire word with a single gesture. This is accomplished by dragging the finger in sequence over the alphanumeric keys corresponding to the characters of the desired word. As soon as the finger passes over a key, the system enters the corresponding character, and also automatically adds a space when the user raises his finger at the end of the gesture.

The space and backspace keys and the suggestion words can be used in both modes only by tapping.

4. Evaluation

We carried out a user-study aimed at evaluating the speed and accuracy of the C-QWERTY layout. To this aim we decided to compare it with the Cirrin layout described in Section 2 and shown in Figure 1.

In the experiment we asked the participants to transcribe some sentences using both layouts (C-QWERTY and Cirrin) and both interactions modes (tapping and gesture).

4.1. Participants

For the experiment, 12 participants (2 female) were recruited. They were all university students between 20 and 28 years old ($M = 23.4$, $SD = 2.4$) and chose to participate for free. All were usual users of computers and smartphones, while most of them had little experience with smartwatches. Most of them also declared a good English knowledge. Figure 3 shows a participant during the experiment.

Figure 3. A participant during the experiment.

4.2. Apparatus

The experiment was conducted on a Ticwatch Pro equipped with a Snapdragon Wear 2100 Quad Core 1.2 Ghz processor and running the Wear OS operating system. The device weighs 58.5 grams and has a circular display with a 1.39" diagonal and a resolution of 400×400 pixels.

The experimental software is a Wear OS application that implements the two layouts (C-QWERTY adn Cirrin) and the two interaction modes (tapping and gesture).

At startup the application asks the user to choose the desired layout and interaction mode. After this selection the application shows for a few seconds the sentence to be transcribed, after which the keyboard that the participant must use to transcribe the sentence is shown. During this phase the sentence is also shown on a computer screen, in order to allow the participant to re-look at it if necessary. After writing the sentence the participant can confirm it by performing a long press over the text field at the center of the screen, after which the system shows the next sentence (or asks the user to transcribe again the same sentence, if he has exceeded the 15% of non corrected errors).

A personal computer with a 19" monitor was used to show the participant the current sentence.

4.3. Procedure

Before starting the experiment, the participants filled out a questionnaire with the following information: personal data (age, gender), dominant hand, the hand with which they actually performed the experiment, previous experiences with smartwatches and with text entry on smartwatches, level of proficiency with the English language.

The experiment was conducted in a well-lit laboratory. The participants were given the watch and told to wear it on the wrist where it was most convenient for them and possibly rest their arm on a desk. Moreover, during the entire experiment they remained seated. Then, they had a short practice session in which the text entry method was explained and tested (fixed example sentences were shown on the pc monitor). The participants were given all the recommendations related to the experiment, and in particular to:

- read and memorize the sentence before starting to copy it;
- balance speed and accuracy when writing;
- correct mistakes made while entering text. Since the only way to correct errors is by using the backspace key, they were also told to avoid correcting errors noticed only after having already written other words.

The measured tasks started after the participants understood the procedure. The task was to transcribe short text sentences. Each participant had to enter six sentences in each of the four test conditions (the first sentence was for training and therefore not measured). The sentences were randomly chosen from the MacKenzie and Soukoreff set [16] that do not include punctuation or numbers. The participants were allowed a rest period of a few minutes at the end of each test condition.

At the end of the experiment the participants were asked to complete a System Usability Scale (SUS) [3] questionnaire for each layout (C-QWERTY e Cirrin). SUS includes ten statements, to which respondents had to specify their level of agreement using a five-point Likert scale. The questions alternate between positive and negative (since they are in a rather standard form we do not include them here). Each SUS questionnaire has a score between 0 and 100, of which we then calculated the averages on all participants.

In addition to SUS, we also asked for the preferred layout (C-QWERTY or Cirrin), the preferred interaction method (tapping or gesture) and the reasons for these choices. We also collected further feedback through an open form and verbal interaction.

Participants	Orderings			
1, 5, 9	QWERTY-TAPPING	QWERTY-GESTURE	CIRRIN-TAPPING	CIRRIN-GESTURE
2, 6, 10	CIRRIN-TAPPING	CIRRIN-GESTURE	QWERTY-TAPPING	QWERTY-GESTURE
3, 7, 11	QWERTY-GESTURE	QWERTY-TAPPING	CIRRIN-GESTURE	CIRRIN-TAPPING
4, 8, 12	CIRRIN-GESTURE	CIRRIN-TAPPING	QWERTY-GESTURE	QWERTY-TAPPING

Table 1. Counterbalancing used during the experiment.

4.4. Design

The experiment was a two-factor within-subjects design. The factors were the Layout and the Interaction mode. The Layout included two levels: C-QWERTY and Cirrin, while the Interaction mode included two levels: tapping and gesture.

As dependent variables we included:

- Speed: text entry speed measured in words per minute (wpm) as specified in [15].
- Accuracy: the text entry accuracy using both the Total Error Rate (TER) and the Non Corrected Error Rate (NCER), calculated as specified in [23].
- GPC (gestures per character): the average number of gestures needed to enter a character (each interaction with the touchscreen is counted as a gesture).

We counterbalanced the two factors, as shown in Table 1.

5. Results

All participants completed the experiment. One participant was unable to successfully use the gesture interaction and basically used tapping when performing the two gesture tasks. For each participant the experiment lasted about 30 minutes. We tested significance using an analysis of repeated variance measures (ANOVA) [8].

5.1. Speed

The text entry speeds are shown in Figure 4. The grand mean for it was 7.2 wpm. *C-QWERTY* was the fastest layout with an average of 8.4 wpm, outperforming *Cirrin* at 6.1 wpm. Regarding the interaction mode, *tapping* was fastest with an average of 7.9 wpm, outperforming *gesture* at 6.6 wpm. Accordingly, the highest speeds were obtained by *C-QWERTY/tapping* at 9.1 wpm and *C-QWERTY/gesture*

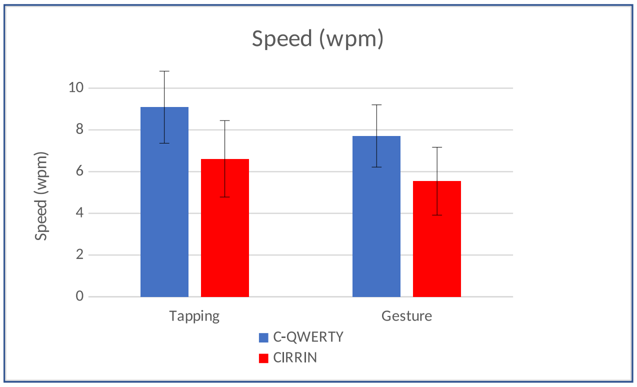

Figure 4. Speeds (in wpm). Error bars show the standard deviation.

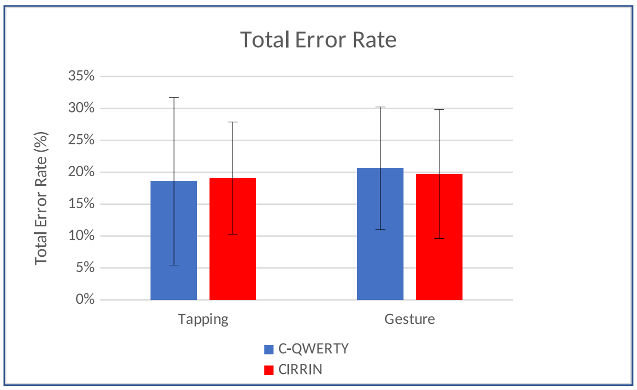

Figure 5. Total error rates. Error bars show the standard deviation.

at 7.7 wpm, while the slowest speeds were obtained by *C-Cirrin/tapping* at 6.6 wpm and *Cirrin/gesture* at 5.5 wpm.

This is probably because in the C-QWERTY mode, the participants could immediately find the position of the letters, given the similarity with the well known QWERTY layout. Moreover the gesture mode is slower than the tapping mode, probably due the fact that some keys are hidden by the hand when performing gestures.

From the ANOVA resulted that the main effect of the layout on the speed was highly significant ($F_{1,11} = 36.546$, $p = .0001$). There was also a significant effect for input mode ($F_{1,11} = 22.865$, $p = .0006$). The interaction between layout and interaction mode was not statistically significant ($F_{1,11} = 0.310$, ns).

5.2. Accuracy

Average values for TER and NCER are shown in Figure 5 and Figure 6.

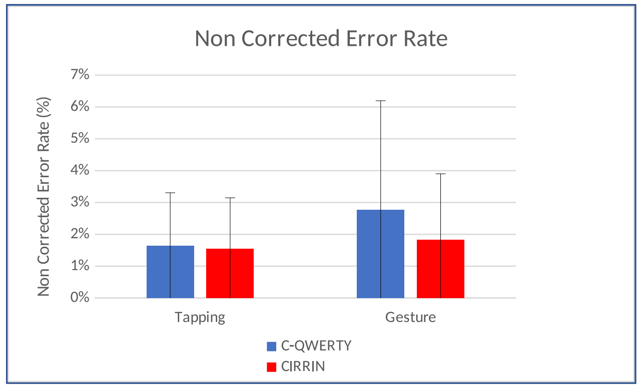

Figure 6. Non corrected error rates. Error bars show the standard deviation.

The grand mean for TER was 19.5%. There was little difference between layouts, with *C-QWERTY* at 19.6% and *Cirrin* at 19.4%. Regarding the interaction mode, *tapping* was more accurate with an average of 18.8%, while *gesture* reached 20.2%. The lowest TER was obtained by *C-QWERTY/tapping* at 18.6%, while the highest by *C-QWERTY/gesture* at 20.6%. However, from ANOVA resulted that there was not a statistically significant difference for the layout ($F_{1,11} = 0.010$, ns), the interaction mode ($F_{1,11} = 0.265$, ns), and the interaction between layout and interaction mode ($F_{1,11} = 0.208$, ns).

The grand mean for NCER was 1.9%. There was little difference between layouts, with *C-QWERTY* at 2.2% and *Cirrin* at 1.7%. Regarding the interaction mode, *tapping* was more accurate with an average of 1.6%, while *gesture* reached 2.3%. The lowest NCER was obtained by *Cirrin/tapping* at 1.5%, while the highest by *C-QWERTY/gesture* at 2.8%. However, from ANOVA resulted that there was not a statistically significant difference for the layout ($F_{1,11} = 1.315$, ns), the interaction mode ($F_{1,11} = 2.151$, ns), and the interaction between layout and interaction mode ($F_{1,11} = 0.455$, ns).

5.3. Gestures per Character

The GPCs are shown in Figure 7. The grand mean for it was 0.94. The *C-QWERTY* layout had the lower value at 0.88, with *Cirrin* at 0.99. Regarding the interaction mode, as expected *gesture* had the lower value at 0.77, with *tapping* at 1.10. Accordingly, the lowest value was obtained by *C-QWERTY/gesture* at 0.67, with the highest value obtained by *C-Cirrin/tapping* at 1.11.

From the ANOVA resulted that the main effect of the layout on GPC was not significant ($F_{1,11} = 1.117$, ns). There was instead a significant effect for input mode ($F_{1,11} = 6.071$, $p = .0315$). The interaction between layout and

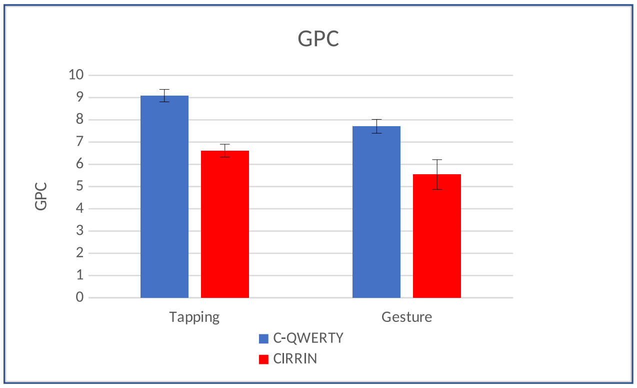

Figure 7. Gestures per Character. Error bars show the standard deviation.

interaction mode was not statistically significant ($F_{1,11} = 0.593$, ns).

5.4. User Satisfaction and Free-form Comments

The average SUS score was 70.0 ($SD = 13.3$) for C-QWERTY and 55.83 ($SD = 12.7$) for Cirrin. A Wilcoxon matched-pairs signed-ranks test [22] performed on SUS scores revealed a statistical significance between the two techniques ($Z = 2.22$, $p < .05$).

The trend on such scores was confirmed by the choice of the preferred layout, with 11 participants that preferred C-QWERTY and only one that preferred Cirrin. Most of them motivated their choice by declaring that the C-QWERTY layout was more intuitive and familiar.

Regarding the interaction mode all participants declared their preference for tapping, stating that in gesture mode it is too difficult to see the keys.

5.5. Discussion

During the experiment, even if most participants had little experience with smartwatches, most participants immediately learned how the method works and showed a fast learning process. To this, it may have contributed the fact that participants were all usual users of smartphones and computers. Moreover, all of them were in the 20-29 age group and university students (some of them even in computer science). This, together with their number (12), may have influenced the obtained speeds in absolute terms, with respect to the general population. However, the relative difference between the different input modes should not have been affected by this.

Most participants preferred the C-QWERTY layout, stating its familiarity as main motivation. This confirms that the QWERTY layout remains recognizable even after its adaptation to a circular layout. All the participants complained about the gesture mode stating that it is too difficult to see the keys and press them correctly. Some participants also complained about the Cirrin layout stating that the position of the characters confused them.

Most of them also appreciated the word suggestion functionality, stating that it was a fundamental help, since it made possible to transcribe the sentences more quickly.

Many of them have instead complained of the lack of a spell checker and of the fact that the entry of a single wrong character is enough to ensure that the desired word will never be shown as suggestion.

However, since the focus of this study is to compare the two layouts and the two interaction methods, we decided to use a simple suggestion feature and not to implement a spellchecker, so that the differences between them could be more directly assessed. Obviously the introduction of functionalities related to a more advanced language model would allow the increase of the writing speed, and for this reason it would be important to use it when comparing C-QWERTY with other text insertion methods that make use of it.

6. Conclusions and further works

In this paper we presented a study comparing different circular layouts for entering text on smartwatches in order to measure the extent through which the use of a circular QWERTY-like layout increases user performance. In particular, we compared our proposed layout C-QWERTY to Cirrin, a layout in which the order of the characters has been optimized to minimize the distance between successive keys during writing. The experimental results show that the C-QWERTY significantly outperforms the Cirrin layout in the first sessions of use.

Future work will focus on the possibility of improving text entry accuracy and speed on circular smartwatch devices by using a specific language model (providing autocorrections). Further experiments will focus on measuring the performance when the user experience increases and on comparing C-QWERTY with other text entry methods.

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