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Estimation of digraph costs for keyboard layout optimization

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ABSTRACT

The main aim of this study was to estimate the digraph costs (interkey-stroke times) based on the digraph (two consecutive keys) tapping rates for the optimization of keyboard layouts considering the touch typing principles. The study also investigated the effects of column, row, hand and period on digraph-tapping rate. For the purpose, a laboratory experiment was performed with seven subjects using a conventional keyboard. Digraph-tapping rates of a total of 241 same hand digraphs were recorded for a duration of 2-min. The interkey-stroke times were calculated as the digraph costs for the same hand digraphs using the estimated mean digraph-tapping rates. The different hand digraph costs were calculated based on the same hand digraph costs and the results of a previous study. The results indicated significant column, row, hand and period effect on the digraph-tapping rate. Using the digraph costs and the digraph frequencies of the considered language in a quadratic assignment problem, an optimal touch typing keyboard layout can be developed to satisfy all but one of Dvorak's touch typing criteria. As an application, an optimal keyboard layout, called Turkish I-layout, is developed for Turkish language. The comparison results between I and existing Turkish F and Q layouts showed that the I-layout is superior both according to the results of the optimization and Dvorak's criteria.

Relevance to industry: Optimal and ergonomic keyboard layouts improve typing performance and reduce the likelihood of upper extremity disorders. The digraph-tapping rates estimated through this study are essential for the development of such layouts.

1. Introduction

Despite considerable advancements in science and technology in recent decades, today keyboards are still in use as the main text entry devices. Number of researchers tried to optimize the layouts of keyboards over the years; however, with some shortcomings. In this study, a new approach to optimize the keyboard layouts for touch typing was proposed. First, touch typing principles were examined and keyboard optimization approaches were covered briefly. Following that, digraph-tapping rates were estimated and the effects of some factors on digraph-tapping rates were investigated through an experimental study. Finally, using the experimentally determined digraph-tapping rates, digraph costs were quantified and then used in a quadratic assignment problem for the optimization of the keyboard layout for a selected language.

1.1. Basics of touch typing

In touch typing, typists type by using the muscle memory without looking at the keys. All the eight fingers are placed on the home row initially; the left hand on the keys "2, 5, 8 and 11" which correspond to "A, S, D and F" in Q layout with the thumb on the space bar; while the right hand on the keys "20, 23, 26 and 29" which correspond to "J, K and L" in Q layout and again with the thumb on the space bar (Fig. 1). Each finger has its assigned keys and the finger returns to its standard position after pressing any of these keys if it is not already on the home row or the finger is not in preparation of another key press.

Touch typing is a very rapid process which includes the parallel movement of fingers. For instance, world champion typists can type at very high speeds up to 200 words per min; and an average professional typist types 60 words per min, which corresponds to five keystrokes per sec (200 ms per keystroke). These interkey stroke times are relatively small compared to the typical choice reaction times. For instance, a study by Salthouse (1984) stated that median interkey interval in touch typing is 177 ms while the median interkey interval for the same subjects in a two-alternative

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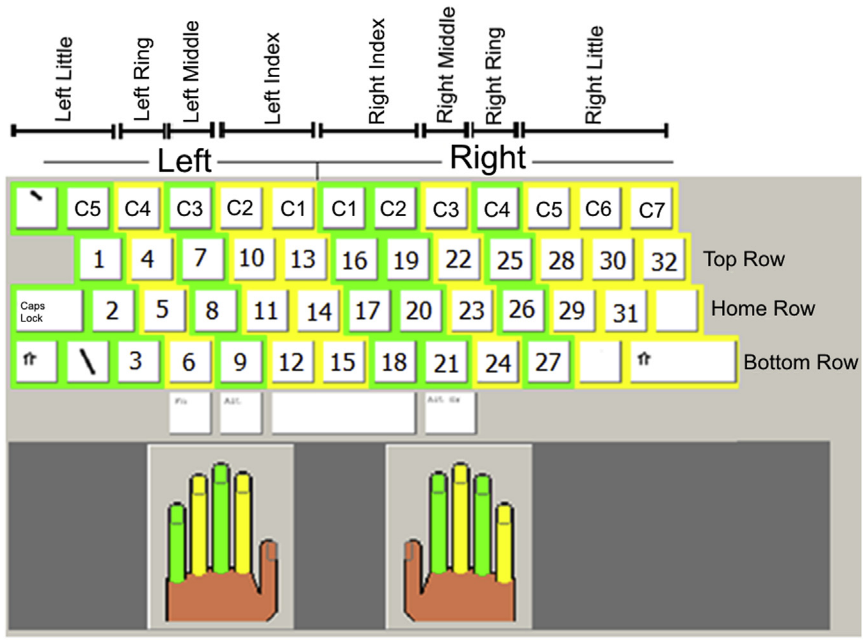

Fig. 1. Key positions, columns and rows on a conventional keyboard.

serial choice reaction time task is 560 ms. This and similar studies from the literature showed that touch typing is not comprised of serial movements of fingers; instead, the movements of different fingers are parallel and overlap in time (Salthouse, 1986). That is, as a keystroke being performed by a finger, the other fingers are simultaneously in preparation of their movements for the next keystrokes.

The span that shows how far in advance of the current keystroke the typist is prepared for the next keystrokes is called as the replacement span and it is highly correlated with the skill of the typist. For professional typists, replacement span is approximately three characters in advance of the current keystroke (Salthouse and Saults, 1985).

Typists are generally 30–60 ms faster when the preceding keystroke is done by the opposite hand than when the preceding keystroke is done by the same hand. This phenomenon was observed by many researchers (e.g., Dvorak et al., 1936; Terzuolo and Viviani, 1980; Gentner, 1981, 1983; Rumelhart and Norman, 1982). This is because when two successive keystrokes are pressed by the same hand, there is little opportunity for the preparation of the next keystroke; and furthermore, if the same finger is used for the successive keystrokes, there is no opportunity at all for the preparation. However, when two successive keystrokes are pressed by the fingers of the alternating hands, as the preceding key is being struck by one of the fingers, the other finger can simultaneously begin its movement toward the next key.

Salthouse (1984) divided the digraphs in four categories and showed the differing performances of each category. He calculated the interkey-stroke times of each digraph category using the professional touch typists (Table 1). As can be seen from the table, the category of the fingers of two different hands takes less time than the others while the category of the one finger non-double takes the longest time.

The same categorization was used in nearly all of the studies for interkey-stroke times such as Gentner (1983) and Heath and Willcox (1990). However, Hiraga et al. (1980) tried to drive a regression formula for all the digraph combinations based on the data on time intervals between keystrokes.

1.2. Keyboard layout optimization

Varying methods have been used for keyboard layout optimization in the previous studies. Most of the earlier keyboard layouts were developed using some heuristic rules while later studies used assignment formulations, multi objective functions and meta-heuristic optimization algorithms. With the use of optimization techniques, keyboard layout design has embarked on a new era. Some well-defined mathematical approaches can be found in the literature for solving the keyboard layout optimization problem (e.g., Eggers et al., 2003; Yin and Su, 2011). Eggers et al. (2003) used six criteria and combined them in an aggregating function for the multi objective optimization of keyboard layouts. On the other hand, they did not use valid digraph cost parameters, instead relied on subjective opinions of a few experts in determining the values of the parameters. Yin and Su (2011) decreased the number of criteria from six to two but used the same parameter values like Eggers et al. (2003).

There are several studies that used QAP model in single finger keyboard layouts such as virtual keyboards (e.g., Ekşioğlu and Soydal, 2010; Uşşak, 2004; Dell'Amico et al., 2009; Li et al., 2006). In these studies, distance matrix of the QAP model was mostly taken as the distance between the keys since in that case interkey-stroke time is highly correlated with the distance between the keys. However, in a touch typing keyboard layout, there is either no or very small correlation between the interkey-stroke time and the

Table 1
Means and standard deviations of median interkey-stroke times for the four digraph categories (Salthouse, 1984).

Digraph Categories	Median (msec)
	$\bar{x}$ (s)
The fingers of two different hands (e.g., “ep” in Q layout)	144 (46)
Two fingers of the same hand (e.g., “ac” in Q layout)	185 (51)
One finger non-double (e.g., “ed” in Q layout)	221 (42)
One finger double (e.g., “ee” in Q layout)	168 (22)