



Residents' numeric inputting error in computerized physician order entry prescription



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ABSTRACT

Background: Computerized physician order entry (CPOE) system with embedded clinical decision support (CDS) can significantly reduce certain types of prescription error. However, prescription errors still occur. Various factors such as the numeric inputting methods in human computer interaction (HCI) produce different error rates and types, but has received relatively little attention.

Objective: This study aimed to examine the effects of numeric inputting methods and urgency levels on numeric inputting errors of prescription, as well as categorize the types of errors.

Methods: Thirty residents participated in four prescribing tasks in which two factors were manipulated: numeric inputting methods (numeric row in the main keyboard vs. numeric keypad) and urgency levels (urgent situation vs. non-urgent situation). Multiple aspects of participants' prescribing behavior were measured in sober prescribing situations.

Results: The results revealed that in urgent situations, participants were prone to make mistakes when using the numeric row in the main keyboard. With control of performance in the sober prescribing situation, the effects of the input methods disappeared, and urgency was found to play a significant role in the generalized linear model. Most errors were either omission or substitution types, but the proportion of transposition and intrusion error types were significantly higher than that of the previous research. Among numbers 3, 8, and 9, which were the less common digits used in prescription, the error rate was higher, which was a great risk to patient safety.

Conclusions: Urgency played a more important role in CPOE numeric typing error-making than typing skills and typing habits. It was recommended that inputting with the numeric keypad had lower error rates in urgent situation. An alternative design could consider increasing the sensitivity of the keys with lower frequency of occurrence and decimals. To improve the usability of CPOE, numeric keyboard design and error detection could benefit from spatial incidence of errors found in this study.

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1. Introduction

Computerized physician order entry (CPOE) is a key health information technology in healthcare [1], in which clinicians directly enter medication and other orders into a computer system instead of using paper [2]. Although the implementation of CPOE has proven to be a significant improvement on medication safety by reducing prescribing errors [3–5], Nanji et al. [6] still found about

one in ten computer-generated prescriptions included at least one error, of which a third had potential for harm. Most of these medication errors were associated with drug doses (68.5%) [7]. Fatal cases have been reported due to numeric entry errors in the popular drug delivery system used in hospital [8]. Health services organizations were seeking to implement computerized order sets to reduce unnecessary practice variation [9,10]. However, overall, the top 20% of order sets accounted for 90.1% of all usage [11]. The integration of Human Factors was still insufficient in the design and implementation phases of CPOE, which was a complex interactive system [12]. The physicians need to input many numbers frequently by keyboard, especially in chemotherapy departments, pediatrics and operation departments. Actually in the clinical settings, the orders are entered into the CPOE either by same or by different person

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who collected them during the visits in the ward. Junior doctors spent most of their after-hours prescribing time transcribing other doctors' orders [13].

Computers were the main equipment used in CPOE operations, including the desktop, laptop, tablet computer, and mobile phone. Despite the advances of computer system processor speed and memory capacity, improvements on input and output equipment were limited. Doctors conducted 93.6% of tasks using stationary PCs, most often within the doctors' office [14]. Touchscreen order system, tablet computer or mobile phone application software, which were still under CPOE supplier's research, have not been widely used in clinical settings. Other alternative data entry devices, such as automatic speech recognition, may be used to avoid manual typing, but they may not have any advantages in error rates and data entry speeds when compared with standard numeric keyboards for numeric data entry [15].

Numbers were often typed based on visual information within a prescription. Residents recorded orders in a ward round and routinely entered orders into CPOE, which assembled the process of transcription typing. In transcription typing, skilled typists can make use of permanent visual presentation to create a running buffer of encoded stimuli (preview) for parallel processing. Therefore, they can self-pace type without feeling much time pressure imposed by the feeding of information [16]. Previous studies in numeric typing have focused on single numbers in hear-and-type tasks [16] and the role of working memory in memorize-and-type tasks [17–19]. The physician would input the orders in another mechanism and have different error patterns. First, inputting order was a combined action of inputting letters, inputting numbers, mouse clicks, and drop-down menu selections, which was a much more complex interaction than the former experimental research that focused on only one typing mechanism. Secondly, the numbers in orders were meaningful to the physician. They were not only digit strings compromising numbers and decimals, but also the drug dosage familiar to the physician.

There were many factors affecting numeric inputting error, including numeric inputting keyboard layout. Many improvements on numeric keyboards have been made to reduce numeric inputting errors. Yan [20] arranged the numeric keys in the middle of the keyboard to provide numeric information and letter keys separated on both sides of the keyboard. Yang [21] used a counter keyboard according to ten colors of a color scale resistor, where each color presented a value for inputting color data. Although these improvements have promoted high inputting speed and have helped reduce inputting error, it was impossible for medical staff to spend a large amount of time to get familiar with these special keyboards. Currently, standard keyboards are widely used in wards. The physician inputs numbers either by number keypad in the small keyboard or by number row in the main keyboard when prescribing in CPOE.

Another important aspect to take into consideration in our experiment was the urgent situation in medical settings. It is generally acknowledged that health care workers have experienced the rescue of critical patients or other time pressure, such as overload or several clients waiting for treatment at the same time. Erroneous keystrokes were possibly caused by an operator's psychophysiological state such as a lack of attention, external distractions, and fatigue [22]. Zenziper et al. [3] found that a large volume of drug prescriptions was associated with a high rate of potential prescription errors, which are common in hospitalized patients and may lead to high significant morbidity, mortality and financial costs. Magrabi et al. [23] examine the effects of interruptions and task complexity on error rates when prescribing with computerized provider order entry (CPOE) systems, and found that complex tasks took significantly longer to complete. In addition, the study found that when execution was interrupted they required almost three times longer to resume compared to simple tasks. It was very difficult in the

laboratory to imitate the emergency in the actual medical environment. A recent study in numeric typing succeeded in using different monetary rewards to manipulate levels of urgency realized by users [16].

The goal of this study was to address the following research questions through an experimentation in which confounding factors in speculation and practice effect were eliminated. First, do residents perform differently using the number keypad versus numeric row in main keyboard in the context of CPOE numeric typing? Second, does the daily prescription behavior lead to higher error rates and imply an inherent difficulty in using other typing strategies? Third, is urgency level an influential factor to consider when it comes to choosing a numeric input method?

2. Material and methods

2.1. Participants

Thirty residents (14 males and 16 females, ages 20–32, with an average age of 24.77 ± 2.60 years old) were recruited via a call for volunteers advertised on the hospital's notice boards. All the participants signed informed consent before the experiment. Each participant was paid for her/his participation.

2.2. Experimental variables

The experiment was comprised of four trials of prescribing tasks, which emulated daily prescription work in a ward. The numeric inputting method variable had two levels: (1) inputting with the numeric row in the main keyboard in which participants could only input numbers using the numeric row in the main keyboard, with a mask covering the numeric keypad portion of the keyboard, and (2) inputting with the numeric keypad in which participants could only input numbers using the numeric keypad, with a mask covering the numeric row portion in the main keyboard. Urgency was manipulated according to the same urgency manipulation method used in our published work in numerical typing area [16]. In that study, we have successfully manipulated urgency levels by two different compensation policies including a flat-rate payment and a performance based reward: in non-urgent situations, the participant received a flat-rate payment independent of her/his performance (15 dollars). In urgent situations, the participant's reward was contingent upon her/his performance for both accuracy and speed. Only correct rates over 90% within 300 s counted as 'passes'. Under urgent conditions, a successful participant could obtain twice the money (30 dollars) that she/he could get in non-urgent trials. To further assure that participants experienced urgency, a countdown counter of 300 s was in the right corner of the screen to emulate what physicians might experience in a clinic if they were stressed by the competitive work, such as a critical condition, operation or clients' complaint.

The dependent variable was mean error rate. When the physician order input in the CPOE did not match the corresponding order presented, or when parts of the physician order were omitted, an error had occurred.

2.3. Experimental task and procedure

Each participant was advised to complete a self-reported questionnaire, a pretest of performance, a sober prescribing exercise, and four trials of prescribing tasks in CPOE system.

2.3.1. Self-reported measures

All participants were asked to complete the following self-reported measures on-site before engaging in the CPOE prescribing task.

- a Demographic questionnaire—this questionnaire was designed to capture information about participants' demographic situation, such as age, gender, education level and clinical practice experience.
- b CPOE prescribing history survey—this measure contained questions regarding CPOE prescribing history, such as estimated CPOE operation time in their daily work, pieces of order by CPOE in their daily work, as well as computer operation preference and habits, such as finger strategies and numeric typing habits.

2.3.2. Pretest and sober prescribing exercise

A pretest, including alphabet typing, numeric typing, pull down menu selection and mouse click, was required before participation to ensure familiarity with computers. They were instructed to finish the pretest within 300s with at least 90% accuracy [16]. In the sober prescribing exercise, participants were then required to type the twenty orders as usual in the simulated CPOE system. The numeric inputting habits, such as the proportion of numeric keyboards usage, were recorded. Table 1 illustrates the self-rating and pretest performance.

2.3.3. Experimental task

All of the orders came from the CPOE system of the hospital where the participants were recruited. We identified a total of 481 pieces of orders. Each order was composed of a drug name, dosage, unit, usage and frequency. For example, when inputting the order “simvastatin 10 mg by oral every day”, the participants need to type the first few letters of the drug name (e.g. simva) and select the desired drug in drop-down menu, input digits (e.g. 10) and decimal into the fill-in-blank field as dosage, and select the corresponding objects in drop-down menu for unit (e.g. mg), usage (e.g. by oral) and frequency (e.g. every day). Orders were randomly assigned into four tasks. The total number of characters for each task ranged from 301 to 452 (with an average of 399.89 ± 36.73 characters).

Stimuli were displayed at on 19-in cathode ray tube (CRT) screens on a Windows XP computer. A manual program running on C++ controlled stimuli presentation. The background was white and the physician order was black. The Font type was Arial and the character size was 12 point, recommended by FDA-Institute for safe medication practices [24]. A piece of physician order was presented in the middle of the screen, one at a time, to avoid the interaction of different lines. To continue typing the next physician order, participants were told to press a button labeled “Next” on the screen. The task sequence was randomly assigned using a counter-balanced design.

Participants were video monitored to ensure that they performed as instructed. The computer program recorded performance in terms of speed and accuracy for later analysis.

2.4. Statistical analysis

This was a 2×2 within subjects design. The incidence of each type of error was illustrated by the ratio of erroneous keystrokes and omission of digits. Error rate in each task was analyzed with repeated analyses of variance (MANCOVA) to see if there were significant covariate, main effects and interactions.

3. Results

3.1. Main effect and interaction

A factorial repeated-measures ANOVA analysis (MANCOVA) showed that, with control of performance in the pretest and numeric inputting habits, numeric inputting method had no main effect on mean error rate ($F_{1,63} = 1.567$, $p = 0.215$), while urgency was found to significantly affect the mean error rate ($F_{1,63} = 87.636$,

$p < 0.001$). The effects of the main factors are plotted in Fig. 1A and B. The nonparallel lines in Fig. 1C shows the significant interaction between numeric inputting method and urgency ($F_{1,63} = 61.482$, $p < 0.001$). In non-urgent situations, inputting numbers with either the numeric row or numeric keypad had similar low error rates (0.36% vs. 0.32%). However, in urgent situations, error rates of inputting numbers using the numeric row was evidently higher than that of the numeric keypad (2.44% vs. 1.88%).

3.2. ANCOVA model

With control of demographics (gender, age, work time, et al.), performance in the pretest (pretest order inputting accuracy and speed) and numerical inputting habits (the percentage of the keystrokes of the numeric keypad in the sober prescribing), effects of keyboard strategies disappeared, and urgency was found significantly effects in the generalized linear model. The result of the reduced ANCOVA model is shown in Table 2.

3.3. Numeric inputting error types

Numeric typing errors were categorized into omission ('10' for '100'), substitution ('150' for '100'), transposition ('105' for '150') and intrusion ('105' for '15'). Fig. 2A illustrates the composition of numeric inputting error types in CPOE. Most errors were omission or substitution type errors, similar to previous studies [16]. But the proportion of transposition and intrusion error types were significantly higher than that of the previous research [16]. A chi square test showed no significant difference between the error types when typing with different keyboards ($\chi^2 = 0.074$, $p = 0.089$). However, a significant difference existed between non-urgent and urgent situations ($\chi^2 = 12.290$, $p = 0.006$). In Fig. 2B and C shows the composition of numeric inputting errors using the numeric keypad vs. numeric row, while Fig. 2D and E shows the composition of numeric inputting errors in non-urgent vs. urgent situations.

3.4. Errors of each digit

3.4.1. Numeric distributions in CPOE prescribing

We found that numeric distributions in CPOE (Fig. 3) were quite different from the traditional numeric inputting task (0–9 single numeric random distribution), which could be accounted for the notable difference in the pattern of error from previous hear-and-type task [16].

3.4.2. Spatial incidence of numeric inputting errors

Fig. 4 and Fig. 5 shows the spatial incidence of numeric inputting errors of different keys when prescribing using the numeric keypad vs. numeric row. We found that the error rates of number 8 and 9 were higher, either in numeric row or numeric keypad inputting. For key 8 and 9, which were the most difficult keys to reach in numeric keypad inputting, the omission error rates of were significantly higher (Fig. 4C). For key 3 and 8, substitution error rates were higher (Fig. 4D). When inputting with numeric row, substitution error rate of key 8 and transposition error rate of key 9 were higher (Fig. 5D and E).

3.4.3. Confusion matrix

Numbers were easily confused with adjacent key or figures similar in shape, both in numeric row and numeric keypad inputting. When inputting numbers using the numeric keypad, numbers were easily confused with others that looked similar (Table 3). When inputting numbers using the number row in the main keyboard, keystrokes were easily confused with adjacent keys, especially when typing numbers of 8 and 9 (Table 4).

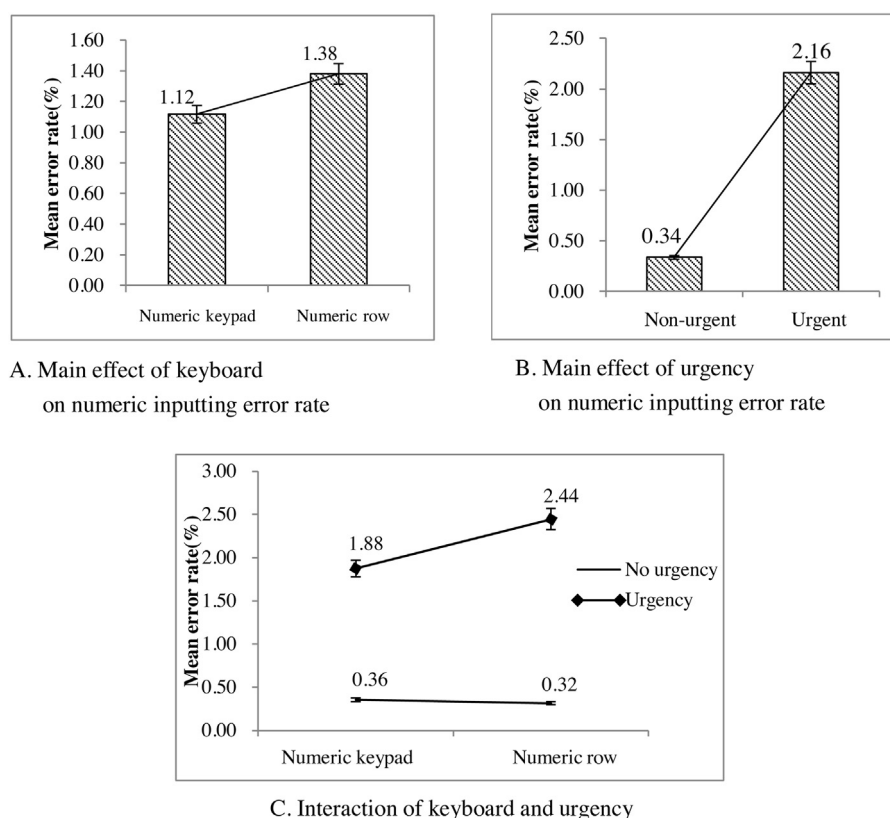


Fig. 1. Main effect and interaction of numeric inputting method and urgency on numeric inputting error rate. (Bars are one standard error from the mean.).

4. Discussion

The current study showed that internalized urgency caused by tangible reward pertinent to inputting performance could have a great effect on numeric input error rate (Fig. 1). Interactions existed between numeric inputting method and urgency. When prescribing in urgent situations, the numeric input error rate using the numeric keypad was significantly lower than that of the numeric row (Fig. 1). It was recognized that inputting using the numeric keypad had lower error rates due to the numeric keypad matching the sequence of the small, familiar keypad of mobile phones [25]. Moreover, demographic characters of the participants, pretest order inputting accuracy and numeric inputting habits were excluded in ANCOVA model, while pretest order inputting speed and pretest

numeric inputting speed entered the model as covariant (Table 2). Based on this framework, we recommend typing numbers using the numeric keypad instead of the numeric row in urgent situations, no matter what numeric inputting habits and demographic characters. Furthermore, we found that in non-urgent situations, inputting numbers with either the numeric keypad or numeric row had similar, low error rates of 0.36% and 0.32% respectively (Fig. 1), suggesting that future efforts to reduce numeric input errors should focus more on research and keyboard design in urgent situations.

Several error phenomena in numeric inputting revealed in this study were compared with Salthouse's findings [26] and Lin's research [16]. An interesting observation was that omission and substitution errors occurred even in non-urgent situations, and the proportion of omission errors increased significantly in urgent

Table 1
CPOE self-rating and pretest performance of participants.

Gender	M/%
Age	24.8
Orders by CPOE in daily work (pieces/day)	21.1
Order inputting speed in pretest (orders /min)	3.9
Order inputting accuracy in pretest (% of correct orders)	98.0
Numeric inputting speed in pretest (keystrokes/min)	96.0
Numeric inputting accuracy in pretest (% of correct numbers)	96.2
Numeric inputting habit (keystroke percentage with numeric keypad in sober prescribing)	70.7

Table 2
ANCOVA model for numerical inputting error rate.

Factor	B	β	t value	P value	R ²
Pretest order inputting speed ¹	1.396	0.494	2.069	0.041 [*]	36.9
Pretest numeric inputting speed ¹	0.001	0.966	3.991	<0.001 ^{**}	
Keyboard	0.241	0.059	0.781	0.436	
Urgency	1.281	0.316	4.136	<0.001 ^{**}	

(Notes: F = 10.609, P < 0.001; ¹ Covariate; ^{*} P < 0.05; ^{**} P < 0.01)

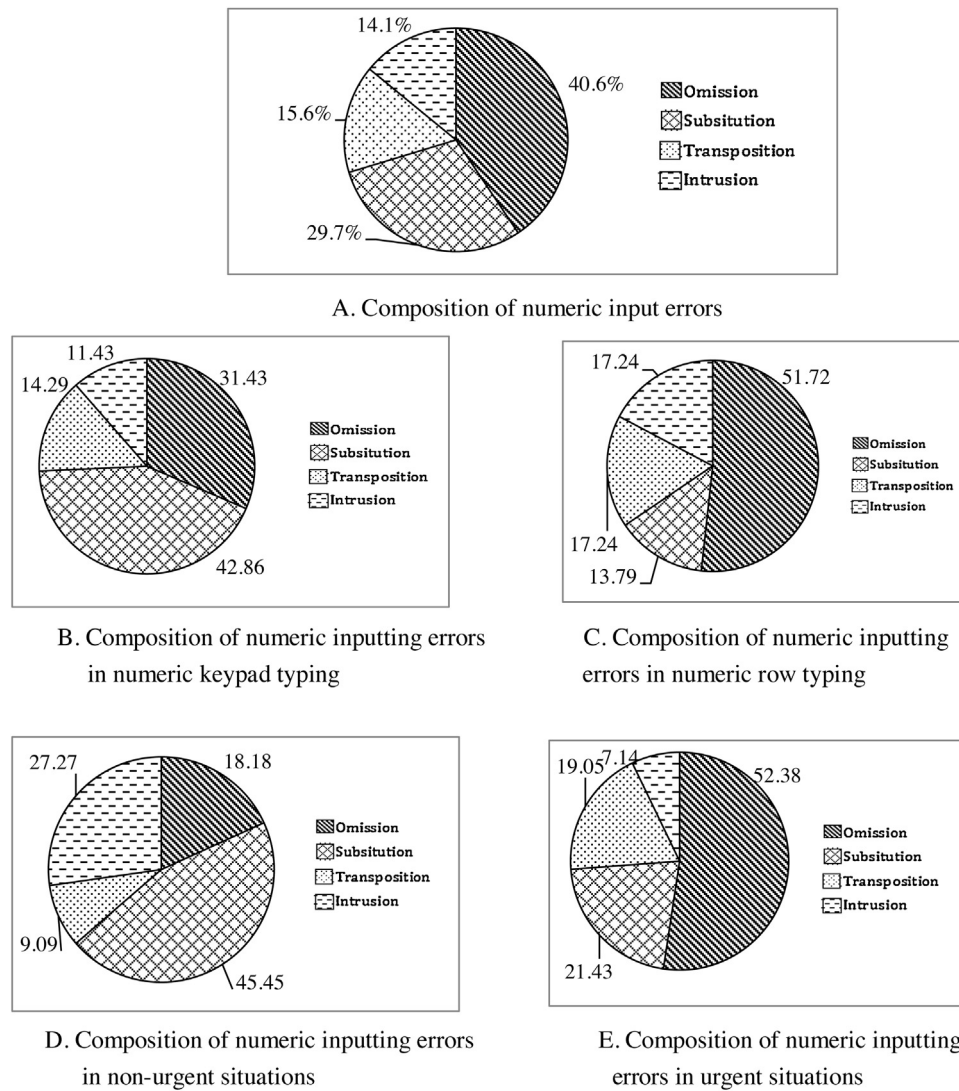


Fig. 2. Composition of numeric inputting errors.

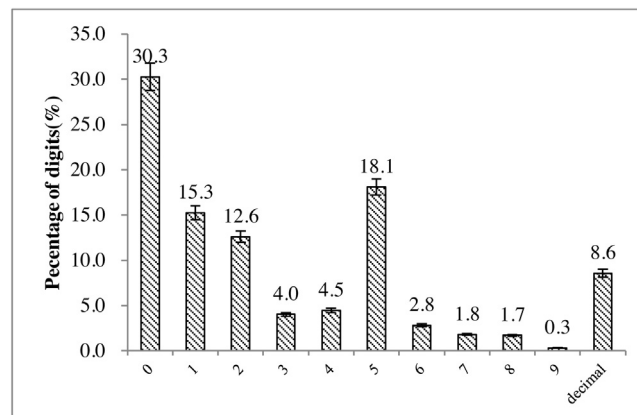


Fig. 3. Numeric distributions in CPOE. (Bars are one standard error from the mean.).

situations (Fig. 2). The spatial distribution of the keyboard layout showed that the pattern of hand movement in which the '8' key and the '9' key were the most difficult keys to reach in numeric keypad typing (Fig. 4). Meanwhile, lower frequency of occurrence

of '3' '8' and '9' keys in CPOE (Fig. 3) demonstrated the residents' lower attention to these keys and less actions of the corresponding fingers. However, when inputting using the numeric row in the main keyboard, although the upper-left and bottom-right corners

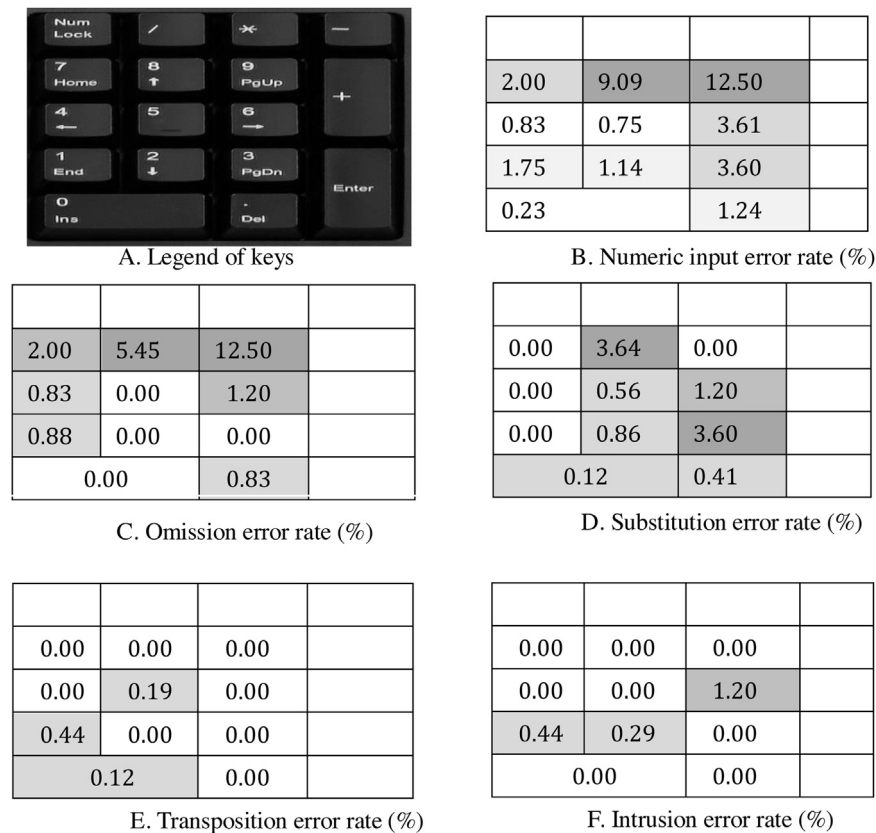


Fig. 4. Spatial incidence of numeric inputting error rate of different keys when prescribing with the numeric keypad (gray scale representing relative concentration of errors; the darker the color, the higher the concentration).

Table 3
Confusion matrix of CPOE substitution errors in numeric keypad inputting (%).

Inputting Stimulus	0	1	2	3	4	5	6	7	8	9	Decimal
0	0	0	0	0	0	0	0	0	0	0	0.12
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0.86	0	0	0	0	0
3	0	0	0	0	0.90	0.90	0	0	1.80	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0.19	0	0	0	0.37	0	0	0	0
6	0	0	0	0	0	0	0	0	1.20	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	1.82	1.82	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
Decimal	0.41	0	0	0	0	0	0	0	0	0	0

were the most difficult positions to reach, keys 1 through 6 had relatively lower error rates while keys 7 through 9 had higher error rates (Fig. 5). Omission of decimals led to ten-fold overdose errors, from one hundred to thousands of times larger than the original dose. However, decimal substitution error, in which zero substituted the decimal point, such as 1.5 represented as 105, produced a nearly 100-fold overdose. Such an error would pose a serious threat

to the safety of patients including fatal consequences [27]. Some improvements in stenographic keyboard device adjusted key depth sensitivity with different depressed position [28]. Sensitivity of the keys means the mechanical tension when pressing and depressing the individual key in the keyboard. The sensitivity adjustment is entirely mechanical by adjusting the depth-of-stroke wheel at the top of each key. An alternative design could consider increasing the

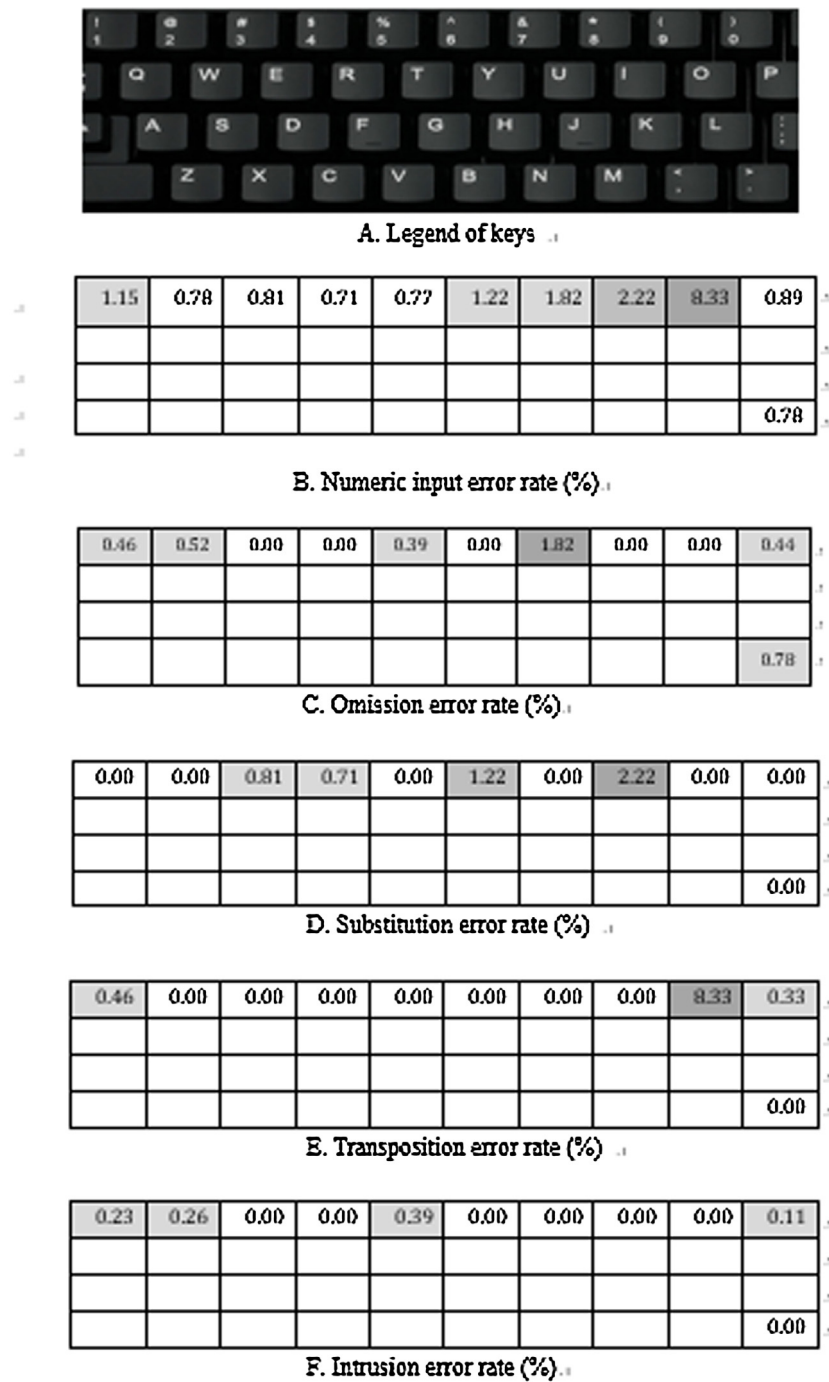


Fig. 5. Spatial incidence of numeric inputting error rate of different keys when prescribing with the numeric row (gray scale representing relative concentration of errors; the darker the color, the higher the concentration).

sensitivity of the keys with lower frequency of occurrence and decimals in CPOE by adjusting the depth-of-stroke wheel at the top of each key, so that different keys have different sensitivity levels.

Although the former research implied that the majority of those confusion pairs were strongly asymmetric [29,30], inputting using the numeric keypad and numeric row generated a different confusion matrix, which may indicate different error patterns. Developers had adopted design practice standards based on human-computer interaction (HCI) research methods rooted in ethnography and cognitive science to avoid the letter-digit confusion [31], however, confusion errors still occurred. When inputting

with the numeric keypad, keys 2, 5, and 8 were located in the center row from left to right, with functional keys on the top. The confusion matrix in Table 2 shows that numbers were easily confused with others that looked similar. When inputting numbers with the numeric row, numbers were easily confused with adjacent numbers, especially with numbers with lower frequency of occurrence, such as 8 and 9 (Table 4). Observations regarding error-prone keys helped us find spatial incidence of error occurrence and contributed to error detection, e.g. paying more attention to error-prone numbers for the medical staff.

Table 4
Confusion matrix of CPOE substitution errors in numeric row inputting (%).

Inputting Stimulus	0	1	2	3	4	5	6	7	8	9	Decimal
0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0.81	0	0	0	0	0	0	0	0
4	0	0	0	0.71	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0.61	0	0	0.61	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0.70	0.70	0	0	0.70	0
9	0	0	0	0	0	0	0	0	0	0	0
Decimal	0	0	0	0	0	0	0	0	0	0	0

This paper does not have any language specific findings and doctors who use COPE speak different languages still need to input numerical information in CPOE, thus we believe the finding has its generality.

4.1. Limitations and future studies

One limitation of this study was that the numeric inputting was performed on a standard numeric keyboard. Whether the results can be applied to other alternative numeric keypads, such as the numeric keypads on touchscreens, needs further investigation. For example, touchscreen keyboards were found to be slower and subject to human errors [32]. Since many improvements on numeric keyboards had been made to reduce numeric input errors, further studies conducted with biophysiological measurements utilizing various keyboard designs are encouraged.

Although the participants in this study were recruited from a real workforce, only residents were included, rather than attendants and chief physicians, due to their long time in the ward and familiarity with CPOE. As is shown in the pretest (Table 1), residents could generate around 100 digits per minute with over 90% accuracy and, therefore, were expected to be representative of skilled prescribers. We need to be cautious when generalizing the results to different working groups regardless of age and typing skills. Educational training programs for the new users should be considered as an indispensable factor for CPOE adoption [33], and staff training was one of a number of factors that were essential to successful CPOE implementation [34]. Meanwhile, older adults showed reduced capacity to process perceptual information during an ongoing response and produced slower movements in tasks of higher complexity, although they were much more skilled and experienced than residents. Delay of responses and degradation of accuracy might be more pronounced in urgent situations for older or less experienced prescribers.

Finally, the experiment was conducted in a simulated CPOE system due to the protection of patient safety. In our experiment, we randomly assigned the 481 pieces of orders into four tasks so that the total number of characters and performance difficulty levels of each task were equal. If the physician input the orders as instruction while the patient did not need this/these order(s), it was very dangerous for the patients. Meanwhile, the experimental protocol

was much more difficult to be designed and data were more difficult to be collected in clinical settings. Consequently, the simulated CPOE system was designed as the interface of the hospital, in which the residents worked. However, it was still not the true order entry system. More field research would be encouraged in the future to reduce the influence of the context information on error rate.

5. Conclusions

This was one of the first experiments of numeric inputting errors for residents prescribing in CPOE system. The results showed that both numeric inputting method and level of urgency were involved in making errors. It was recognized that inputting with the numeric keypad had lower error rates in urgent situations. In non-urgent situations, however, inputting numbers with either the numeric keypad or numeric row had similar, low error rates, which means that urgency could play a more important role in error-making than typing skills and typing habits. The results suggest that future efforts to reduce numeric input errors should focus more on research and keyboard design in urgent situations. In addition, the analysis of error patterns revealed that error-making mechanisms in alphabetical typing or numeric typing in hear-and-type tasks did not necessarily translate to numeric typing in CPOE prescribing. Both spatial distribution of the keyboard layout and frequency of occurrence of the digits were attributable to typing errors. An alternative design could consider increasing the sensitivity of the keys “3, 8, 9”, “2, 5, 8” in numeric keypads, and decimal. CPOE mechanical engineers’ understanding on error prone keystroke will be covered by our research. An alternative numeric typing keypad design or touch screen number entry with radio buttons specific for medical staff may contribute more to prevention of wrong dose error in the future.

Author contributions

Xue Wu and Changxu Wu designed the study. Xue Wu collected and analyzed the data. Changxu Wu, Kan Zhang and Dong Wei monitored the progress of the study and vetted the results at each stage. Dong Wei prepared the experiment procedure and vetted by Xue Wu and Changxu Wu.

Summary points

What was already known on this topic?

- CPOE prescription errors still occur.
- Physicians need to input many numbers by keyboard when prescribing and standard keyboards are still widely used in wards.
- Physicians often experience the rescue of critical patients or other time pressure.

What this study added to our knowledge?

- Inputting with the numeric keypad has lower error rate in urgent situations.
- Both spatial distribution of the keyboard layout and frequency of occurrence of the digits are attributable to numeric inputting errors.
- An alternative numeric keypad design could consider increasing the sensitivity of the keys “3, 8, 9”, “2, 5, 8” and decimal.

Conflicts of interest

There is no conflict of interest in this study.

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