Subitizing-Counting Analogue Observed in a Fast Multi-tapping Task

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Abstract. A widely-used method for entering texts with mobile phones is the multi-tapping one. To understand the internal processes of humans while doing multi-tapping, we designed an experiment with time pressure, that is, to multi-tap a key for the prescribed number of times as fast as possible. We observed three types in time series data for inter-tap intervals: Type I (Plan and Do), Type II (Do and Adjust), and Type III (Mixture of Type I and II). And, for the distribution of errors in the tapping, we found a subitizing-counting analogue. That is, if the instructed number of tapping was smaller (< 4), the error rate was smaller, and if the number was larger (> 4), the error rate rose abruptly. These findings could lead to the model of human cognition and manipulation of the number, hence to the design of the usable human interface.

Keywords: subitizing, counting, numerosity, cognitive process, text entry, mobile phone.

1 Introduction

Despite the popularity of full keyboards in mobile information devices, a lot of people still use the multi-tapping methods for text entry with mobile phones. The multi-tapping is the method of entering letters by pressing keys for multiple times [1]. When you write an e-mail with your mobile phone, you need to tap the keys multiple times. When, for example, you want to enter the letter "a", you tap the key "2" once. And when you want to enter the letter "c", you tap the same key three times. In the case you want to enter the letter "A" (capital A), the usual way is to tap the key four times, and if "C", tap six times. In the standard assignment of the English alphabet, the key "9" is for the letters "w", "x", "y", "z". Thus if you want to enter "Z", you have to tap the key eight times. In the English text entry, three letters are assigned to each of the key "2" through "9" with the exception of four letters to the key "9". Depending on the language, the assigned number of letters per key varies. In Japanese, for example, basically five letters are assigned to the keys "1" through "0" excepting three letters to the key "8" and "9".

To simplify the argument, we designed an experiment in which the participants were instructed to tap a single key for the prescribed number of times as fast as possible. Surely it is too simple, since in reality the text entry task involves several sub-tasks such as "determining the appropriate key", "searching the key visually", "targeting the key", and "tapping the key for the appropriate number of times". The present study focuses on the last sub-task of the text entry procedure.

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When we react to the number, i.e. recognize the number of objects presented visually, it is known that we switch between the two modes according to the number we have to recognize. For the number less than or equal to four, we use subitizing, and for the number greater than four we use counting. To put it simply, subitizing is the one-shot recognition of the number requiring tens of milliseconds per object, and counting is a sequential procedure requiring hundreds of milliseconds per object [2]. The subitizing-counting mode is not specific to visual stimuli, but observed in auditory stimuli as well [3].

A major finding of the present study is that there is subitizing-counting analogue in the results of the fast-tapping task. We found the human error distribution in fast multi-tapping, which is analogous to the subitizing-counting of numerosity recognition.

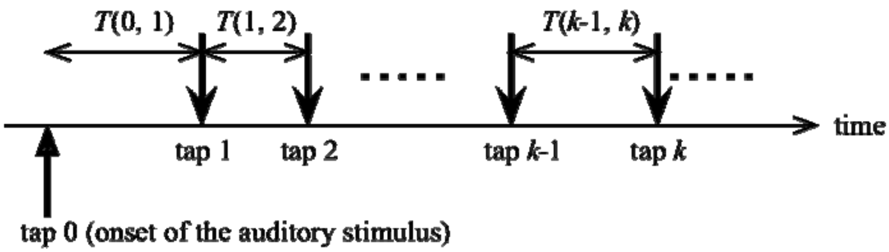


Fig. 1. Explanation of the inter-tap intervals $T(k–1, k)$

2 Experiment

Sixteen volunteers participated in the experiment. All were university students at the age of 22–24. The participants tapped a single key on the computer keyboard as fast as possible for the prescribed number of times. To minimize the other factors than just tapping, we used auditory stimuli that say “one”, “two”,..., and “nine” with the recorded human voice. And there were no visual or auditory feedback while performing the task. Stimuli were presented thirty times for each participant in the random order. Time series of every key tap were monitored by and stored in a personal computer.

The results are summarized in the following from two points of view. One is the type of time series of inter-tap intervals, and the other is the error distribution over instructed number of taps.

3 Results

The results are summarized in the following from the two points of view. One is the type of time series of inter-tap intervals, and the other is the error distribution among prescribed number of taps. First we show the inter-tap interval time series, and then show error distribution.

3.1 Time Series of Inter-tap Intervals

Inter-tap intervals are the time between successive taps $T(0, 1)$, $T(1, 2)$, ..., $T(k-1, k)$, ..., $T(n–1, n)$, where “tap 0” is the onset of the auditory stimuli (no tap) and n is the prescribed number (See Fig. 1). In Fig. 2, three types of responses from the participants are shown schematically. By noticing the lines connecting $T(0, 1)$ and $T(1, 2)$, we categorized the data into three types:

1. Type I (Plan and Do). There are longer delays in doing the first tap, and then, according to the plan, the successive taps are made feedforwardly.
2. Type II (Do and Adjust). The participants of this type seems just start the procedure and adjust in the course of tapping, probably using (cognitive?) feedback.
3. Type III (Mixture of Type I and II). Type I and II behaviors are not distinct.

In Fig. 3, typical three examples of responses from three participants are shown.

3.2 Error Distribution

Let us look into the error in the number of taps. First we show , in Fig. 4, the distribution of the participants (16 persons in total) with respect to error-making rate. Most (69%) of the participants make less than 10% errors. The relationship between the error and the prescribed number of tapping is summarized in Fig. 5. We can see the abrupt rise in the error rate at $n = 5$. The errors are divided into two types: "too much" and "too few". In Fig. 5, "too much" errors are shown as white bars, and "too few" errors are as black bars.

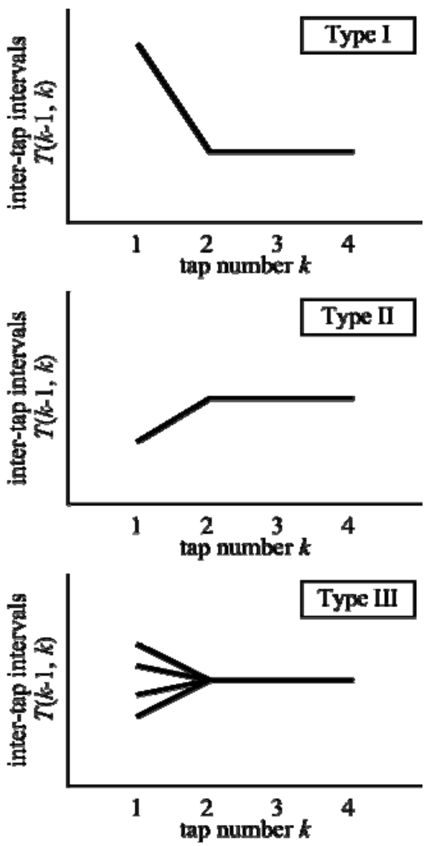
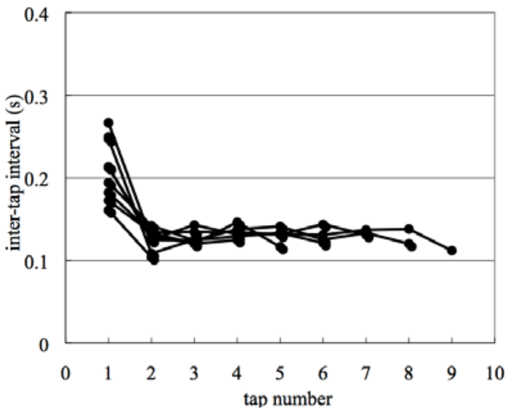
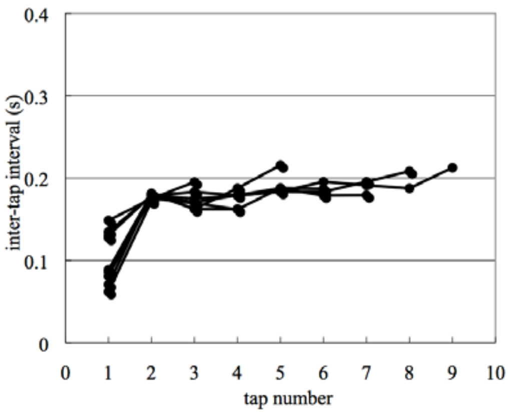


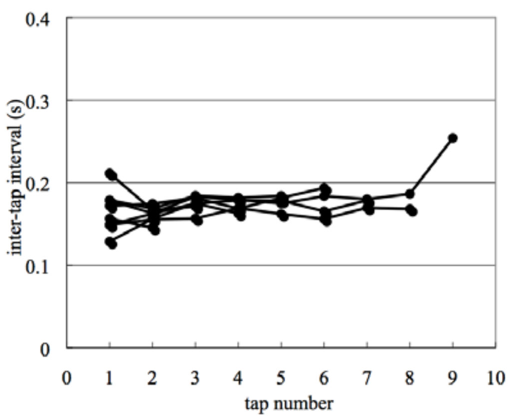
Fig. 2. Three types of time series data. Time series data of the inter-tap intervals are categorized into three types by focusing on the relationship between T(0, 1) and T(1, 2)



(a) An example of Type I.



(b) An example of Type II.



(c) An example of Type III.

Fig. 3. Inter-tap interval vs. tap number for Types I, II and III. Time interval between the tap k–1 and k, T(k–1, k), is plotted as a function of tap number k.

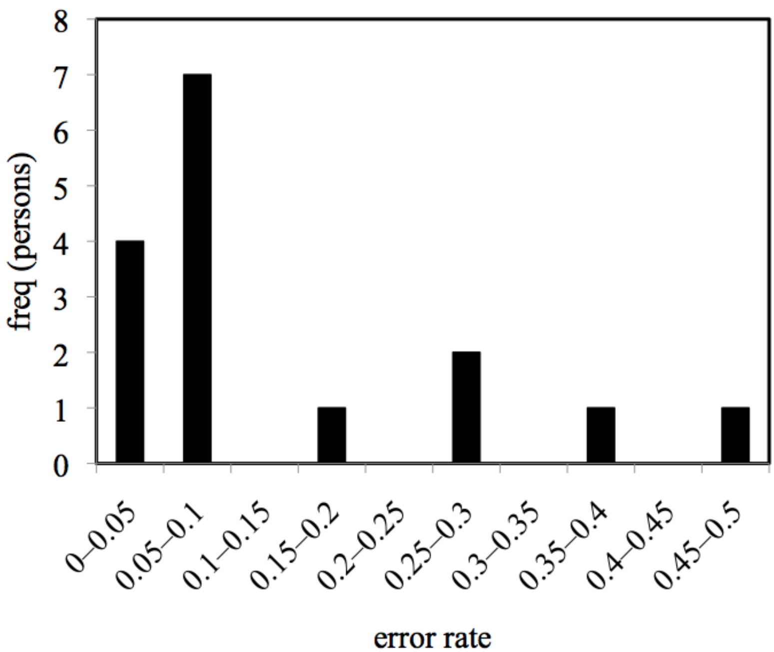


Fig. 4. Distribution of the participants with respect to error rate

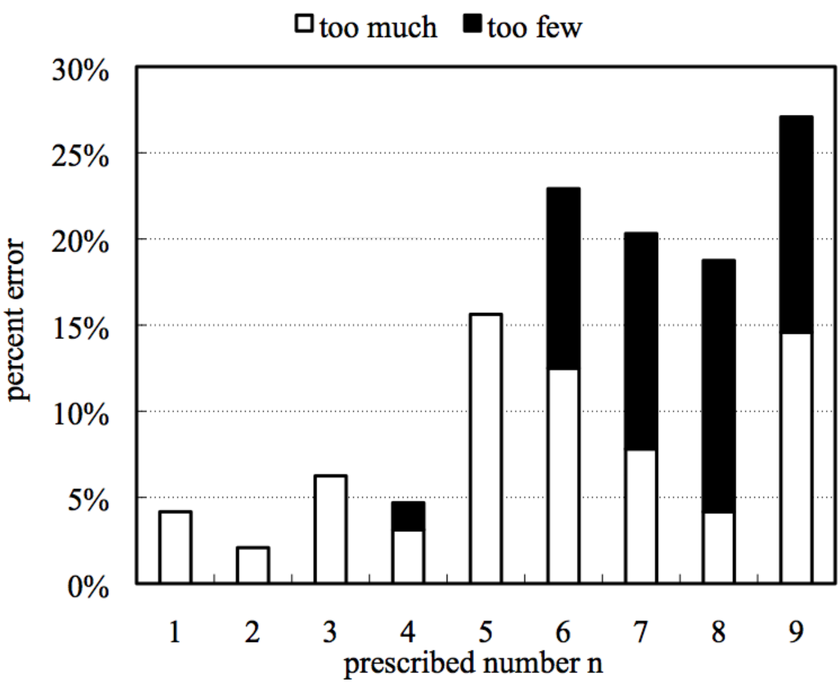


Fig. 5. Error rates averaged over all participants and all trials

4 Summary and Discussion

We investigated time series of inter-tap intervals for the tapping task with time pressure (the participants are to tap prescribed number of times as fast as possible). Looking into the time series of sixteen participants, we tentatively categorized the data into three types. That is, Type I (Plan and Do), Type II (Do and Adjust), and Type III (Mixture of Type I and II). We are just starting the analysis of the data to discuss the validity and the meanings of these types. We are also doing in-depth analysis of the time series of inter-tap intervals in comparison with the simple reaction time and the "Model Human Processor" by Card et al. [4]. The error distribution of Fig. 5 is reminiscent of subitizing-counting modes in enumerating the number of visual objects. That is, in the subitizing range (1–4 in average) you can answer the number of the objects instantly, and in the counting range (5 and over) you have to count up sequentially, hence the time needed to answer the number tends to much longer than in the subitizing range. In enumerating, if there is a time pressure, errors are inevitable in the answer. Thus, we say the present result for error rate is analogous to subitizing-counting characteristics of human behavior. Of course, there is an essential difference between enumerating the objects and multi-tapping of a key. That is, whereas the former is the process of recognition, the latter is of planning and action. We have to analyze the data further in detail with a view to separating the underlying processes. One of other things to consider is doing the same line of experiments by using visual cues instead of auditory ones. We have just gathered the data for the same experiment which uses two different keyboards (difference is in the force needed to press the key), to investigate the effects of the keyboard on the time series of inter-tap intervals and the distribution of errors.

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