The internal structure of university students' keyboard skills

Joachim Grabowski

University of Education, Heidelberg, Germany

Abstract: Nowadays, university students do not necessarily acquire their typing skills through systematic touch-typing training, like professional typists. How, then, are the resulting typing skills of university students structured? To reveal the composition of today's typical typing skills, 32 university students were asked to perform three writing tasks: copying from memory, copying from text, and generating from memory. Variables of keyboard operation that presumably reflect typing abilities and strategies were recorded with ScriptLog, a keystroke logging software; these variables include typing speed, keyboard efficiency, and keyboard activity beyond keypresses that become visible in the final text. Factor analyses reveal three components of typing behavior per task. The clearest interpretations of these components concern keyboard activity/efficiency and typing speed. Across tasks, typing speed is the strongest individually stable facet of keyboard operation. In summary, university students' keyboard behavior is a multi-faceted skill rather than the mere mastery of a touch-typing method.

Keywords: typing, keyboard efficiency, academic writing, keystroke logging

journal of
WRITING RESEARCH

Grabowski, J. (2008). The internal structure of university students' keyboard skills. *Journal of Writing Research, 1* (1), 27-52. http://dx.doi.org/10.17239/jowr-2008.01.01.2

1. Introduction

While education during primary and secondary school adheres to handwriting as an important facet of an individual's cultural socialization, students in higher education institutions have, for decades, no longer been allowed to submit handwritten work. Rather, typed manuscripts are required. This change in academic customs may be due to several reasons. Typewriters – invented at the end of the 19th century with the standardization of work processes – became more adaptable (less weight; less physical exertion through electrification; less expensive) and thus more readily available for individual use. Their typeface had far better legibility than many handwriting styles, and the regularity of lines and spacing generally looked better. Moreover, by means of carbon paper it was possible to produce a (small) number of copies from one typing act, already before photo-copying became prevalent. In those times, however, it was more typical than today for students either to take special touch-typing training (Gentner, 1983), or to have typists copy handwritten manuscripts for them. (Remember the thousands of books and theses with forewords in which authors thank their spouses for typing their manuscripts.) Using a typewriter was to a large extent seen as a professional skill comprising the proper use of all ten fingers, a certain typing speed (expressed in numbers of words or keystrokes per minute), and the ability to press the correct keys without visual control. Since pre-electronic typewriters had no mechanism for the correction of strokes, the precision of the finger movements and of their temporal succession played an important role (Rieger, 2004).

With the advent of the computer, however, things have changed (Kellogg, 1994, pp. 140-160; MacArthur, 2006). Meanwhile, it has become commonplace to not equate the computer with an electronic typewriter. Particularly, text processing software has influenced the whole process of text generation to the extent that now many authors compose their texts directly on the keyboard. Since the authors of texts generally have a profession different from that of a typist (former typists did not even have to understand the texts they were copying), they have rarely invested in touch-typing training.

Nevertheless, one can become a kind of skilled writer simply through the frequent use of a keyboard. Since there are many individual ways and methods of achieving satisfying, sufficiently automated typing fluency, however, there is no longer the one professional typing skill, taught at vocational schools and colleges, according to the standardized instructions of how to position the fingers on the middle row of the keyboard and how to move up and down to type the letters of the other rows with the designated fingers (see Rieger, 2004, p. 556 for the typing system on a German QWERTZ keyboard; Gentner, 1983, p. 235, for the typing system on an English QWERTY keyboard). Moreover, writing on the computer generates virtual traces of script which can be easily edited, deleted, or corrected. Thus, mistyping on the computer is less serious with respect to a presentable product than mistyping on the traditional typewriter. Fluent correction skills, for example, can compensate for the limited precision of keystrokes.

Our modern world is full of keyboards and displays. Today's university students made their first contact with keyboards during their early socialization processes, not only – or not at all – through education. Many people did not even become aware of the fact that the order of the nine numerical keys is different on pocket calculators and computer keyboards compared to mobile phones and remote controls, but they skillfully operate both layouts. Moreover, today's students have become familiar with the computer keyboard not only as an arrangement of keys for the creation of letters, punctuation marks, and blank spaces, but also as a tool with functional keys for deletion, correction, and navigation within a text, for the creation of upper- and lower-case letters, and for jumps to particular places in a text like the beginning or the end of a line or paragraph. Thus, skilled keyboard use may be more than – or even different from – good mastery of a keyboard's letter array.

In a preparatory study, for example, we found that only one of 30 above-average university students performed on a copy task without regularly looking back and forth between the given text and the computer screen and/or the keyboard. For meaningful text, copied chunks contained some 17 characters on average, ranging from 11 to 27 characters per gaze, which is still far from touch-typing without visual control. For meaningless text in a foreign and unknown language, chunk size dropped to an average of 7, exactly Miller's (1956) magical number of short-term memory capacity. Moreover, copying speed in the typing mode did not even exceed handwriting fluency. Although these students had passed a difficult selection process and were mastering their studies very successfully, and although they did not consider themselves unpractised with respect to keyboard and computer use, their typing skills and strategies were far from those of professional typists (Grabowski, 2007).

What is the result of the educationally uncontrolled acquisition of keyboard skills in university students? Which typing behaviors did they develop? Are there different patterns and strategies? This has not yet been studied extensively. Is it justified to leave it to the students how, and to which end, they acquire typing skills during their (partly educational) socialization? Being higher education instructors, we only see the final texts that our students submit, the quality of which – if they are written by the students themselves – certainly reflects the respective student's effort and understanding. But we do not see how the physical trace of typing came into being. Writing research could reveal the benefits of some typing strategies as opposed to others, perhaps suggesting that universities include typing in the basic study skills they spend efforts to shape and develop. The study presented below is not intended to evaluate such strategies with respect to criteria like text quality or educational success. Rather, it is a first attempt to systematically describe existing strategies. To that end, we will apply factor analysis to a wide range of keyboard behavior variables across simple writing tasks in order to reveal underlying patterns of typing strategies.

2. Perspectives on typing skills

To date, typing skills have been studied from different perspectives. These perspectives differ, among other things, with respect to the scale of the writing processes considered. Most of the available studies refer to the temporal patterns of keystrokes. A frequent measure is the interstroke interval. This measure relates to the fact that, while handwriting is a continuous action, typing is composed of discrete events of keystrokes, separated by intervals of keyboard inactivity (Gentner, 1983, p. 234). This does not mean that there is generally no psychological activity between two subsequent keystrokes; but it is clearly observable, with respect to the technical effect, which key has been pressed at which time. Meanwhile, there is ample keystroke logging software which substantially supports the registration and analysis of temporal typing patterns (Sullivan & Lindgren, 2006a, 2006b). According to theoretical considerations, longer interstroke intervals are often referred to and interpreted as pauses (e.g. Wengelin, 2006).

However, these temporal patterns of keystrokes and pauses can be explained on different levels of potential causes (Salthouse, 1986). As mentioned, traditional professional typists predominantly engaged in transcription writing, or copying (also referred to as copytyping; Inhoff & Wang, 1992). With copying tasks, the processes of planning and formulation can be neglected. In hierarchical models of the entire writing process, such processes are located on high and medium levels (Fayol, 1999; Grabowski, Blabusch & Lorenz, 2006; see Alamargot & Chanquoy, 2001, for an overview of writing models). Therefore, the observed keystroke intervals can be attributed to the very skills of typing; with more complex tasks, they would also, or even mainly, reflect higher-order processes of text production or of language production as such (e.g., Spelman Miller, 2006). (In very low-ability typists, or beginners, the search for the next letter on the keyboard can, of course, eclipse any other processes.)

2.1 The biomechanical approach

On a most basic level, the temporal patterns of skilled typing have been related to finger movements for subsequent keystrokes as determined by the prevalent touch-typing method, i.e. whether or not the next key is pressed by the same hand or finger etc. Here, it was shown (e.g. Gentner, 1983; see already Coover, 1923) that the interstroke intervals of very skilled typists were limited by biomechanical constraints, in part effective because of the particular layout of standardized keyboards. (Note that our common keyboards reflect universal, but not ideal solutions for typing at maximum speed.) Moreover, Rieger (2004, 2007) found for skilled keyboard writers that keypress behavior is activated already upon the perception of letters, and that this automatic activation is strongly based on effector-specific representations (i.e., which hand and which finger is involved in the typing of the respective characters). Following this line of research, the relation of eye movements to finger movements has also been studied (Inhoff & Gordon, 1997). Here, the most relevant measure of eye-hand span relates to the fact that, in professional typists, the fixated letter is on average three letters ahead of the concurrently typed letter (see already Butsch, 1932). Inhoff and Gordon (1997) show that the eye-hand span is, in part, a function of the biomechanical constraints of typing (see also Inhoff & Wang, 1992)..

2.2 The linguistic approach

Beyond these peripheral determinants of temporal typing patterns, there is also evidence of lexical effects: high frequency words are generally typed faster than less frequent words (Gentner, Larochelle & Grudin, 1988; Inhoff, 1991). Moreover, the influence of further linguistic units below and above the level of words (syllables, morphemes, constituents) and their boundaries on the temporal keystroke succession has been put forward (Nottbusch, Weingarten & Sahel, 2007; Weingarten, Nottbusch & Will, 2004). Again, almost no planning and formulation processes were required in the respective studies. Although these authors do not explicitly say much about the typing experience of the participants in their experiments, it seems that a certain degree of good (although not necessarily professional) typing skill is a prerequisite of the linguistic factors of written words or sentences to systematically determine the time course of keystrokes.

2.3 The cognitive approach

While the two above-mentioned approaches to typing studied biomechanical and linguistic variables, a third approach relates to cognitive processes. Torrance and Galbraith (2006) give a comprehensive account of the various processes that can be responsible for the cognitive demands of writing. One common assumption is that high-level as well as low-level components of the writing process can place a load on working memory, and that with increasing load by one component, performance based on other components suffers when they rely on the same processing resources (Just & Carpenter, 1992; Kellogg, 2001). In this context, skilled typing means that the typing process as such is so automated that it does not require much, or any, attentional resources. If, for example, the visual search for the next letter on the keyboard is an attention-demanding process, performance on any cognitively demanding task will decrease when the result of this task is to be conveyed via typing. Thus, Hayes and Chenoweth (2006) show that articulatory suppression (which blocks a part of working memory functions) impairs the speed and accuracy of transcription writing. Note, however, that their study only admitted participants who were able to type at least 40 words per minute, which is a considerable semi-professional pace. Below, we will show that today's typical keyboard use exceeds mastery of the letter array and includes other keyboard functions, for example deletion and navigation, which have not been represented on traditional typewriters' keyboards.

In the framework of the cognitive approach, it has been shown that children, but also adults, perform better on memory tasks in the spoken mode as compared to the (hand-) written mode (Bourdin & Fayol, 1994, 2002), indicating that writing is cognitively more costly than speaking. Penney and Blackwood (1989) found different patterns of serial recall when comparing handwritten and typed recall modes; low typing skills were held responsible for the non-appearance of recency effects. Grabowski (forthcoming) showed that memory span performance in university students decreases under conditions of typed recall, when their typing skills are artificially de-automated by exchanging the location of ten frequent keys on the keyboard. Between writing modes, Grabowski, Blabusch and Lorenz (2007) found that low-ability fifth- and eighth-graders in secondary modern school copied texts faster and more precisely by hand than on the keyboard; many students were lacking basic keyboard skills like using the space bar, generating upper-case characters, correcting mistyped characters, or navigating by use of the arrow keys. In summary, skilled typing means – from the perspective of cognitive processes – being able to think and type at the same time without losses.

2.4 The differential approach

Good typing skills are based on many practice hours and can still improve over years (Inhoff & Gordon, 1997). Therefore, the differences between more and less skilled (or unskilled) keyboard writers and the effects of these differences on any aspect of complex writing processes and the resulting products cannot be studied in experimental designs with random assignment of participants to groups of skilled and unskilled writers. At most, an unpractised writing mode can be experimentally induced, as already mentioned above, by exchanging letter keys in typing, or by forcing participants to use some uncommon handwritten script (Bourdin & Fayol, 1994; Grabowski, forthcoming; Olive & Kellogg, 2002). Such artificial conditions, however, can at best cause impairment of otherwise well-functioning processes, allowing for only indirect conclusions about the functioning of the processes under investigation. In contrast, Alves, Castro, de Sousa and Strömqvist (2007) used the natural distribution of varying typing skills among Portuguese college students to compare, after a median split, slow and fast writers. Here, typing speed was taken as the decisive feature of typing skill. Participants wrote narratives based on the pictures of the often used "frog story" (Mayer, 1969). The authors found that the slower writers spent more time pausing, due to a higher overall number of pauses, whereas fast writers had longer periods of coherent execution. Combining the two results, the authors found a significantly higher ratio between pausing time and execution time to be a typical characteristic of skilled keyboard writers: for a given amount of execution time, slow writers pause almost twice as long as fast writers. In order to explain these findings, a lack of automaticity in typing is considered to be the main factor.

2.5 Summary

For a summary and integration of the approaches to typing skills reviewed above, two aspects are worth noting. First, the three first-mentioned approaches have in common that they search for law-like interrelations: whenever somebody is a skilled keyboard user, his or her typing pattern underlies certain biomechanical constraints, is influenced by certain linguistic determinants, and is so automated that other cognitive processes can run in parallel without interference. Second, these insights come mainly from writing tasks which were rather simple with respect to the complexity of the processes involved, namely transcription of already existing texts, repetition of predetermined words or sentences, or recall of word or sentence lists from memory. The fourth-mentioned approach has different, if not opposite, characteristics. It aims at systematic differences between typing individuals. Moreover, it studies complex writing processes of narratives, but confines the notion of typing skill to the mean transition time between two subsequent keystrokes within a word. All other keyboard activities were not considered in the classification of participants.

Below, we will report on a study intended to fill this research gap. It combines a differential perspective with a broader consideration of keyboard activities. As mentioned above, there may be several kinds of typing skills in today's students beyond the standardized touch-typing method. Particularly, typing skill does not only comprise letter strokes, but mastery of all the keys and functions of a computer keyboard. Imagine a very fast writer who very often hits the wrong key, but also very quickly corrects his typos. Is he more or less skilled than another writer who is slightly slower but never mistypes? Both may have the same average speed with respect to their final text products. Or what about somebody who has very fast keystroke intervals within words, but is very slow at navigating to a certain position in the already written text to correct or revise something? Or are these questions irrelevant and meaningless because the imagined constellations would never exist in real writers? Which aspects of typing behavior and keyboard use occur together? Which components of typing skills appear to be independent from one another? In our study, we aimed to detect and describe the existing patterns of keyboard use and keyboard mastery in university students.

3. Methods

Given the above-mentioned research questions, we designed an experiment in which each participant performed on three different tasks of varying complexity and cognitive demands. On a most general level, we looked for patterns of keyboard behavior that occur across the different tasks, so that they can be assumed to reflect stable individual typing skills and strategies rather than task characteristics. Different from the above-mentioned approaches to typing skills which were predominantly interested in typing speed in the form of interkey intervals, we also considered those keyboard variables, characterizing functions of computer keyboards, that have not been available with typewriters.

3.1 Participants

Thirty-two female teacher students of Heidelberg University of Education participated in the experiment, with a mean age of 23 years. None of them had a professional background as a typist. They performed on the tasks in individual sessions. Participants knew that the study was about temporal patterns in typing. They received a reward of five Euros for approximately 30 minutes.

3.2 General procedure

All participants worked on three subsequent writing tasks in the same order of increasing complexity. On the occasion of the instruction of the first task, they were shown an empty text input window of ScriptLog 1.8.22 for Windows on a 17" computer screen in front of them. ScriptLog is software for keystroke logging, devised by a group of Swedish researchers from the University of Lund (Strömqvist et al., 2006), which registers the temporal succession of keystrokes and offers many predefined analytical tools related to speed, pausing, deletion etc. (and has recently been expanded to eye-tracking analysis; see Andersson et al., 2006). Participants were informed that the text window functions like text processing software, but without formatting options. Moreover, they had no mouse available, so cursor movements on the screen also needed keyboard operations. The start and stop functions of ScriptLog for the recording of the respective writing sessions (three per subject) were operated by the experimenter.

3.3 Tasks

With complex writing tasks that involve high-level processes such as idea generation, developing arguments, linearization of concepts, or consideration of rhetorical demands, to name but a few, an individual's overall typing progression depends on many factors other than basic typing skill. Therefore, it is rather the time between coherent "bursts" of keystrokes (= pause analysis) than the time within continuous typing that is being analysed when complex task performance is studied under keystroke logging. In our study, however, we tried to eliminate as many of the higher-order processes involved as possible in order to make the very low-level skills of keyboard operation most visible. The most natural task is what Inhoff (1991) calls copytyping and what most of the studies summarized in section 2 have used: presenting a text pattern that is to be copied via the keyboard, the typical task of former professional typists. The details of the task that we used in our study are described below as "Task 2: Copying from text".

But this is not the least complex typing task imaginable. Although you do not have to generate ideas, plan or formulate when copytyping, it is not only the manual skill of typing and the mastery of a touch-typing method that is responsible for the speed and precision of task performance. It is also the visual and temporal coordination of reading the text pattern (in suitable portions) and reproducing it on the keyboard. It could be that students – who are after all not preparing to be copytypists – do not manage this part of the task well due to a lack of copy practice, although they are very experienced in keyboard use as such. Therefore, we also devised a task in which this kind of eye-hand coordination demand is removed. This task is described below as "Task 1: Copying from memory".

In order to having a typing task that is, like the two aforementioned tasks, simple enough to allow for mainly continuous typing progression but that at the same time is not confined to words and formulations set in advance, we added a task that needs some planning and formulation but that relates to information very easily retrievable for each student from long-term memory, along with a naturally given sequential organization that would minimize the demands of linearization processes during text production. This task was describing one's way from home to the university. Below, this task is described as "Task 3: Generating from memory".

Task 1: Copying from memory. Participants were shown a printed text pattern with twelve consecutively numbered repetitions of the first sentence of a very well-known German nursery rhyme ("Alle meine Entchen schwimmen auf dem See", the German cultural literacy counterpart to "Mary had a little lamb"). This task was introduced as a kind of typing baseline. Participants were instructed to write this sentence twelve times in consecutive lines and to number the lines from 1 to 12. At the end, the written product should look like the presented pattern, which was removed from the participants' sight before they started to write. Altogether, the text pattern consists of 531 characters (including blanks and punctuation marks). We assume that this task did not involve any planning or formulation processes, with lexical retrieval processes likely to be very rapid and effortless because the rhyme is so over learned that it can be largely recalled without consciousness.

Task 2: Copying from text. Next, participants were asked to copy a stylistically not very difficult text of 1170 characters and 156 words about the legend that German only narrowly lost in a vote about the US-American official language. The text, printed on a sheet of paper, remained beside the keyboard. Participants were instructed to avoid errors if possible, and to proceed carefully without dawdling. This is a typical transcription task, the processes involved like those described above.

Task 3: Generating from memory. Finally, participants were asked to write a description of the route from where they live to the university building as if somebody had asked them: "How do you get from your apartment to the university?" For this writing task, some planning as well as formulation processes were needed. However, we expected that the processes of idea generation, conceptualization and linearization would not prove very difficult because students know their daily route, and because a route already offers a linear organization that strongly guides the text structure (Denis et al., 2001). Since participants were asked to describe their way from home to the university, and not to give an instruction for the reader to find that way, writers were (correctly, as it turned out) expected to spend not too much time and effort on problem solving in order to ensure the functional quality of their texts

3.4 Analysis

ScriptLog logfiles store the sequence of keystrokes and the related time progression; they also offer a replay function which makes the original typing process visible. From these recordings, predefined analysis tools provide a range of variables describing the registered writing sessions in many respects. Supplementary analyses were calculated by hand on the basis of the measures provided. In order to capture the relevant characteristics and variants of the resulting patterns of the educationally uncontrolled acquisition of typing skills, we considered three groups of variables: (a) variables that refer to the frequencies with which certain groups of keys are used during typing, (b) variables that refer to the speed of keyboard use during typing, and (c) variables that refer to the quality of the final text. Whereas in text generation research, final texts are most often rated for their quality of composition, the quality of a copytyped text is its agreement with the given text pattern. All variables that will enter factor analyses are computationally and empirically mutually independent, except for one added variable derived from other measures, keyboard efficiency, which appears to reflect important differences between individual strategies of keyboard use. For illustration, we will also descriptively report some meaningful compound variables. All variables were computed separately for each of the three writing tasks.

Frequency measures

With respect to text production, the keys of a typical computer keyboard fall into three functional categories: keys that create a character (henceforth: characters); keys that remove an already created character (henceforth: deletions); and keys that change the position on the screen where the actions of other keys become effective (henceforth: cursor movements). Characters include numerals, upper- and lower-case letters, blank space, punctuation marks, and logographs (<§>, <$>, <%>, <&>, etc.). <RETURN> also creates a character that affects the display of the text and, thus, becomes visible. Concurrent combinations of <SHIFT>, <CONTROL>, <ALT> or <ALT GR> with other keys, which change the character produced by the respective key, are treated as one keystroke. Deletions include <BACKSPACE> which removes the preceding character, and <DELETE> which removes the next character, relative to the current cursor position. (Interestingly, many students never use the <DELETE> key, but rather move the cursor to the right in order to then use <BACKSPACE> deletion.) Cursor movements include the four arrow keys as well as <POS 1>, <END>, <PAGE-UP> and <PAGE-DOWN>. Moreover, there are a couple of function keys <F1> to <F12>, <ESC>, <Print>, etc., which do not play a role in text production and which are not further considered. Finally, the numerical keypad only replicates functions already represented elsewhere on the main part of the keyboard.

As a main statistical value, ScriptLog calculates the total number of keystrokes, referring to the overall number of keystrokes of all kinds while performing the task. Numerically, the total number of keystrokes is the number of characters in the final text plus the number of cursor movements plus twice the number of deletions (because the use of a deletion key always removes one already typed character). While the number of characters in the final text is strongly influenced (although not entirely determined – see precision variables below) by the task, there are two degrees of freedom left for the consideration of frequency measures:

1. Number of deletions. This measure counts all strokes of backspace and delete keys; it is considered an inverse indication of typing precision.
2. Number of cursor movements. This measure refers to changes of the cursor position by arrow keys (and other cursor-positioning keys which are, however, seldom used by students). It reflects a writer's general navigation activity. However, the occurrence of much or little navigation activity can have different reasons. Little or no navigation can be either due to very precise typing which doesn't need any revision, or it can indicate that a writer simply doesn't revise. Much navigation will reflect lively revision activities, but can also reflect low keyboard mastery insofar as it takes a lot more key operations to trace back the already written lines with the left arrow key only (as some writers do) instead of finding one's optimal way to a certain position in the text by the proper combination of all available arrow directions. The reason responsible for a certain amount of cursor movements, however, becomes apparent through the correlation with other variables indicating deletions and precision. For example, if university students typically typed at a highly error-free level, little navigation and high precision quality of the final text would co-occur. If many cursor movements are used for a small number of deletions, however, this would indicate low arrow-key mastery.

Speed measures

Interstroke intervals have been the predominant measure in previous research on typing skills. Here, the most general variable is time on task, referring to the time elapsed from the first keystroke to the last keystroke. Time on task, however, is to a substantial degree co-determined by the task itself; longer text patterns take longer to copy than shorter ones. This task influence can be removed when dividing time on task by the total number of keystrokes, resulting in time per keystroke, a variable that indicates general keyboard mastery. However, it is known that the best assessment of maximum typing speed relates to the interkey intervals – or transition times – within words. While the initial letter of a word, as well as punctuation, spaces, and keyboard operations other than letters (deletions, navigation), often reflect delays due to planning, retrieving, verifying, or editing processes, the average interstroke intervals from the second to the last letter of every written word are considered the most basic indication of typing skill in its narrow sense. Beyond transition time within words, we will also report on another, computationally independent variable which reflects the interkey intervals between any two keys that do not represent subsequent letters within a word. This variable is called transition time other and is intended to indicate the speed of keyboard operation beyond the mere typing of linguistic units. When the values of the two

transition time variables are multiplied with the number of keystrokes within the respective group of keys, the sum of the two products yields time on task.
The distribution of transition times between subsequent keystrokes is often steep on the left and skewed to the right, where they merge into long intervals that can be interpreted as pauses. Therefore, ScriptLog calculates 5%-trimmed means within a writer's protocol. However, these means are normally distributed across subjects, so we will report regular arithmetic means of transition times. After all, we will consider two computationally and empirically independent variables of typing speed:

3. Transition time within words: This measure refers to the mean of the interkey intervals between subsequent letters within a word. It reflects typing skill in its narrowest sense. Since transition times within words are typically skewed to the right, we will report 5%-trimmed means.
4. Transition time other: This measure refers to the mean of the all interkey intervals between subsequent keystrokes except when both keys represent a letter. It reflects the skill of general keyboard operation, particularly with respect to functions other than the creation of words. Since in the distribution of these interkey intervals both extremes are interesting (very short transitions at the left end upon the repeated use of arrow keys and deletions; longer transitions at the right end due to pauses), we will report regular arithmetic means.

It was already mentioned that the study of pauses received particular attention in writing research. Most often, pauses in writing are defined as keyboard inactivity longer than 2 seconds (e.g., Wengelin, 2006). Such intervals probably reflect processes beyond the mere motor behavior of writing. Alves et al. (2007) showed that the proportion of pausing time (above the criterion of 2 coherent seconds) differs between what they call slow and fast typists. Therefore, we will consider the relative pause time as another variable of typing speed. The proportion of pausing time relative to time on task, rather than the absolute pausing time, is computed in order to make this measure comparable across different tasks. Although pauses are, from a certain perspective, nothing other than longer interkey intervals which mainly occur at word boundaries and which therefore may be already covered by the transition time other variable, their proportion of the total time on task is neither determined by nor derivable from the computation of transition times.

5. Relative pause time. This measure is the sum of all pausing times during task performance relative to time on task, where a pause is defined as an interkey interval of two or more seconds.

Text quality measures

As mentioned above, the quality of a copytyping product is its agreement with the text pattern. The degree of this agreement can be assessed in two respects, namely quality and quantity. The quality of the copied text is related to the absence of typing errors. Vice versa, the number of typing errors that remained in the final text reflects a deviation from optimal quality. In the case of copy tasks, typos are easily defined as every character in the final text that differs from the text pattern. With a free writing task such as our third task, generating from memory, it is more difficult to define typing errors. Here, every obviously mistyped character (as opposed to mistakes from possible lack of knowledge of orthography or punctuation) will be considered an error. However, we refer to error units because there are typical mistyping phenomena, such as the confusion of two characters, which are based on one wrong typing aspect, although such a typing mistake results in two different characters with respect to their original order. Superfluous or missing blanks or returns are not counted as errors if they only affect the formal shape of the text.

Omitted passages in the second task (copying from text) are not counted as typing errors; this deficit is considered in a variable that reflects the quantitative aspect of text quality. Although in copy tasks the number of characters in the final text appears to be set by the task, it is empirically still open whether writers reach that intended number or whether they exceed or undercut it due to a lack of precision. Therefore, this aspect of copying precision is measured through the absolute value of the difference between the number of characters in the text to be copied and the actual number of characters in the resulting text. For the text generation task, the quantitative aspect of text quality can only be represented by the length of the text, i.e. the number of characters in the final text. Here is the summary of the variables indicating text quality:

6. Number of errors in final text. This measure is the number of typing error units that remained in the final text.
7. (Deviant) number of characters in final text: This measure refers to the quantitative aspect of the final text's quality. With free writing tasks, it simply reflects the length of the text. With copy tasks, it reflects one aspect of the correctness of the transcript. If the number of edited characters exceeds or falls below the number of characters in the pattern to be copied, something must be wrong with the transcript, and the value of this variable will exceed zero (absolute deviation from optimum).

Variables (1) to (7) indicate different aspects of the typing process; they are computationally independent from one another. However, we will add one variable that is computationally derived from already existing measures, because we assume that it nevertheless reflects important differences in the typing strategies of non-professional, but experienced keyboard users. Moreover, consideration of this variable allows to connect to the results of Hayes and Chenoweth (2006, p. 140) where a similar measure refers to "wasted keystrokes".

8. Keyboard efficiency: This measure is computed as the proportion of the number of characters in the final text relative to the total number of keystrokes. Maximum keyboard efficiency is 100 per cent which means that every single keystroke left a trace in the final text. When the final text is defective, however, high keyboard efficiency means that the writer did not correct or edit the text. Generally, keyboard efficiency reflects the amount of keystrokes needed to produce a certain amount of

final text; it is considered a measure of an individual's habitual keyboard operation during writing. Since the total number of keystrokes is composed of the number of characters in the final text, the number of deletions, and the number of cursor movements, keyboard efficiency will necessarily be positively related to the amount of deletion and navigation. However, it is empirically open which of these and other variables show the highest correlations with varying typing efficiency.

4. Results and discussions

4.1 Task 1: Copying from memory

Table 1 shows the descriptive analyses of the aforementioned variables for the first task, copying a nursery rhyme twelve times in succession. For two participants who erroneously repeated the sentence only ten rather than twelve times (which can be taken as a result of poor memory rather than poor copying processes), variable values were proportionally extrapolated to keep these data comparable, and rounded off when whole numbers are appropriate. Variables in rows with a grey background are reported to create a more illustrative impression of the data; they will not enter subsequent analyses.

Table 1. Descriptive analysis of keyboard operation: measures for task 1: copying from memory (n = 32)

Variable	Minimum	Maximum	Mean	Standard error
N keystrokes total	543	893	601.72	13.58
N deletions	0	29	9.22	1.28
N cursor movements	0	300	36.84	11.89
Time on task (sec)	84.1	202.3	138.71	4.95
Transition time within words (sec)	.125	.239	.167	.006
Transition time other (sec)	.176	.448	.295	.011
Relative pause time (%)	0	10	2.01	0.41
N errors in final text	0	1	.13	.06
Deviant N of characters	0	20	1.84	.77
Keyboard efficiency (%)	62	98	89.54	1.56

The speed variable "transition time within words" shows that all participants could be classified as rather fast typists, e.g., in the framework of Alves et al. (2007). However, this only holds in a context of "lay typists"; about half of our students would not meet the 40 words per minute criterion of the study of Hayes and Chenoweth (2006). Again, this shows that large parts of the existing research do not apply to typical academic writers. Almost no error occurred in the final texts, and the amount of pausing was very small. Nevertheless, even with this simple task there are substantial inter-individual differences in the number of deletions and cursor movements, so that the writers' keyboard efficiency (number of keystrokes needed to produce a certain amount of final text) significantly varies. To reveal the underlying patterns of the observed variation, the variables introduced in section 3.3 (except for "number of errors in final text" which has almost no variance) were submitted to a principal component factor analysis with subsequent varimax rotation according to Kaiser's criterion. The termination condition was set to initial eigenvalues above .9 that explain at least 10 per cent of variance. Table 2 shows the underlying correlation matrix, Table 3 shows the resulting factor loads.

Table 2. Correlation matrix for task 1: copying from memory (N = 32; * and ** indicate significance below .05 and .01)

	N cursor movements	Transition time words	Transition time other	Relative pause time	Deviant N of characters	Keyboard efficiency
N deletions	.324	–.173	–.338	–.312	.257	–.504**
N cursor movements		.118	–.259	–.039	.468**	–.942**
Transition time words			.605**	.116	–.156	–.014
Transition time other				.402*	–.333	.339
Relative pause time					–.207	.014
Deviant N of characters						–.385*

Table 3. Factor loads for task 1: copying from memory

	Component		
	1	**2**	**3**
N deletions	.480	–.152	–.535
N cursor movements	.960	.061	–.003
Transition time words	.075	.949	–.002
Transition times other	–,293	.781	.337
Relative pause time	.034	.108	.940
Deviant N of characters	.563	–.258	–.201
Keyboard efficiency	–.964	.035	.029
Explained variance	35.6 %	23.1 %	18.9 %

The solution comprises three factors with a cumulative explanation of 77.7 per cent of variance. With respect to simple structure as a criterion of interpretability, 14 out of 21 factor loads are above .80 or below .20.

The first component receives its strongest contributions from the number of cursor movements, and it is strongly negatively associated with keyboard efficiency. Together, this factor reflects the amount of activity when operating the keyboard, with much activity leading to small efficiency. This factor will henceforth be called the keyboard activity/efficiency factor. In contrast, the second component clearly reflects typing speed, with the two transition time measures being the leading variables. This is called the typing speed factor. The third component is mainly loaded by two variables, namely the temporal proportion of pauses above two seconds, and the number of deleting operations with a negative sign. Transition times for keys other than letters within words also make a small contribution to this factor. This pattern does not point to an interpretation as easily as the other two components. However, the combination of little deletion and more frequent pausing, along with some degree of slower typing for non-linguistic keyboard function, can be tentatively interpreted as a factor reflecting caution and prudence which may be a characteristic of varying typing precision.

It appears particularly interesting that the transition time within words, considered in previous research as the most decisive characteristic of typing skill, has loadings of around zero on both the first and the third factor. Thus, there are further systematic sources of variance in typing behavior which support our view of a broader concept of typing skill.

4.2 Task 2: Copying from text

Table 4 shows the descriptive analyses for the second task, copying a coherent text.

Table 4. Descriptive analysis of keyboard operation measures for task 2: copying from text (n = 32)

Variable	Minimum	Maximum	Mean	Standard error
N keystrokes total	1110	2021	1375.53	38.62
N deletions	2	114	42.22	4.69
N cursor movements	0	718	113.38	31.04
Time on task (sec)	267.3	632.9	418.91	15.71
Transition time within words (sec)	.148	.273	.194	.006
Transition time other (sec)	.168	.721	.458	.026
Relative pause time (%)	2	32	12.15	1.38
N errors in final text	0	15	3.19	.63
Deviant N of characters	0	109	11.75	4.53
Keyboard efficiency (%)	58	99	86.02	1.96

Transition times within words are again rather fast, but clearly longer than those of professional typists, who can reach interstroke intervals of about 100 milliseconds (Gentner, 1983). The huge differences in pausing times may reflect different strategies in taking over text portions from the original. There are also strong inter-individual differences with respect to keyboard efficiency and the related variables (number of deletions and cursor movements).

All variables were submitted to a factor analysis as explained with task 1. Table 5 shows the underlying correlation matrix, Table 6 shows the resulting factor loads.

Table 5. Correlation matrix for task 2: copying from text (N = 32; * and ** indicate significance below .05 and .01)

	N cursor movements	Transition time words	Transition time other	Relative pause time	N errors in final text	Deviant N of characters	Keyboard efficiency
N deletions	.194	−.555**	−.477**	−.121	.190	−.131	−.481**
N cursor movements		−.241	−.516**	.312	−.210	−.152	−.939**
Transition time words			.708**	.280	−.014	−.088	.405*
Transition time other				.477**	.005	.153	−.477**
Relative pause time					−.245	−.081	−.268

Table 6. Factor loads for task 2: copying from text

	Component		
	1	**2**	**3**
N deletions	−.672	−.151	.317
N cursor movements	−.298	−.891	−.003
Transition time words	.858	.078	.134
Transition times other	.895	.239	−.039
Relative pause time	.576	−.652	.004
N errors in final text	−.153	.410	.654
Deviant N of characters	−.058	.259	−.779
Keyboard efficiency	.477	.842	−.111

The solution comprises three factors with a cumulative explanation of 76.0 per cent of variance. The resulting matrix of factor loads shows a moderate degree of convergence to a simple structure; 11 out of 24 factor loads are either above .80 or below .20. The first factor has substantial loads of many variables except those indicating the quality of the final text. Certainly, typing speed is most clearly reflected in this factor. But slow typing (within and outside of words) appears not only to occur together with more pausing time, but also with less deleting operations (which to some degree raises keyboard efficiency). Vice versa, fast typing appears to co-occur with much deleting, which is plausible insofar as fast typing may increase the probability of mistyping. However, this correlational pattern is obviously independent of the quality measures of the final text; these are unambiguously represented in the third factor. (This rotated factor solution also nicely shows that factor analyses can reveal connections that remain invisible in correlation matrices; here, the two measures of final text quality showed a correlation not substantially different from zero.) The second factor combines high positive loads of keyboard efficiency with high negative loads of cursor movements and pausing time, thus referring to keyboard activity and efficiency. (Note that, although keyboard efficiency is derived from both the number of deletions and the number of cursor movements, the second factor connects the empirical occurrence of keyboard efficiency almost solely to the occurrence of cursor movements.)

Comparing the first and the third factor gives rise to the suspicion that there may be two different strategies with respect to precision. While the first factor includes loads of variables related to the accuracy of the typing process, the third factor consists of variables related to the precision of the text product. Both patterns of typing characteristics appear to be mutually independent.

4.3 Task 3: Generating from memory

Table 7 shows the descriptive results for the third task, describing one's way from home to the university. As justified in section 3.4, the deviant number of characters in the final text, a variable appropriate for copy tasks, is replaced by the number of characters in the final text.

Table 7. Descriptive analysis of keyboard operation measures for task 3: generating from memory (n = 32)

Variable	Minimum	Maximum	Mean	SE
N keystrokes total	276	1638	726.78	56.355
N deletions	3	85	34.94	4.26
N cursor movements	0	304	84.28	19.31
Time on task (sec)	72.4	652.5	216.76	22.14
Transition time within words (sec)	.132	.270	.183	.007
Transition time other (sec)	.175	.939	.411	.148
Relative pause time (%)	4	36	20.11	1.47
N errors in final text	0	8	1.50	.33
N of characters in final text	210	1452	567.81	45.94
Keyboard efficiency (%)	40	96	78.98	2.64

Compared to copy tasks, an unrestricted writing task leads to different lengths of the resulting texts which is reflected in the spectrum of the frequency variables. But also with the relative variables, there are large inter-individual differences, particularly relating to deletion, navigation, and keyboard efficiency. Pausing remains far below the proportion of 40 or more per cent of the entire writing time which is often reported for text composition tasks. Explaining well-known facts – the route from one's home to the university – does not appear to require difficult planning processes or much idea generation (Torrance & Galbraith, 1999) which would cause longer pauses.

All variables were committed to a factor analysis as explained with task 1. Table 8 shows the underlying correlation matrix, Table 9 shows the resulting factor loads.

Table 8. Correlation matrix for task 3: generating from memory (N = 32; * and ** indicate significance below .05 and .01)

	N cursor movements	Transition time words	Transition time other	Relative pause time	N errors in final text	Deviant N of characters	Keyboard efficiency
N deletions	.023	–.152	–.166	–.216	.286	.543**	–.137
N cursor movements		.343	–.397*	.114	.057	.079	–.834**
Transition time words			.355*	.186	–.011	–.043	–.259
Transition time other				.560**	.053	.196	.588**
Relative pause time					–.126	.105	.003

Table 9. Factor loads for task 3: generating from memory

	Component		
	1	**2**	**3**
N deletions	–.100	–.281	.784
N cursor movements	–.934	.131	.091
Transition time words	–.392	.663	–.062
Transition times other	.536	.799	.077
Relative pause time	.004	.789	–.061
N errors in final text	.003	–.016	.658
Deviant N of characters	.103	.174	.856
Keyboard efficiency	.961	.106	.079

The solution comprises three factors with a cumulative explanation of 73.8 per cent of variance. 16 out of 24 factor loads are above .80 or below .20. For the first extracted component, the leading variables are the number of cursor movements and keyboard efficiency, which indicates the factor of keyboard activity and efficiency that has also been found with task 1 and 2. The second component is the typing speed factor; individuals differ with respect to the basic keyboard mastery which shows up in the intervals they need for keystrokes of all kinds. The fact that the proportion of pausing time loads positively on the same factor, is in agreement with the finding of Alves at el. (2007), according to which slower typists have higher proportions of pauses than faster typists. The third component seems to reflect the amount of written text, indicated by the numbers of characters in the final text. However, numbers of remaining typing errors and number of deletions go together with this variable, although they rather indicate typing precision. But this may be a matter of probability. The more you type, the more often you will mistype, and this is either corrected (= delete), or remains unnoticed (= error).

4.4 Comparisons across tasks

So far, we have seen that for all three tasks – copying from memory, copying from text, and generating from memory – a three-component structure emerged from the factor analysis of a representative sample of variables that reflect keyboard behavior in a broader sense. The observed factor loads suggest interpreting two of the extracted components in each instance as keyboard activity/efficiency and typing speed. Since the resulting factors, after varimax rotation, are orthogonal to one another and thus have zero correlations, there appear to be – with all three investigated tasks together – at least two, possibly three mutually independent facets of keyboard mastery.

Given the reported experiment and results, there are at least three methods to investigate whether or not individual habits and characteristics of keyboard mastery are stable across tasks. First, correlations of identical variables across tasks will indicate the stability of inter-individual differences in keyboard behavior. Second, repeated measurement analyses of variance across tasks will show, for relative measures that do not depend on absolute numbers, the stability versus instability of individual keyboard behavior. Third, we can study the inter-correlations of the factor scores across the three tasks. This method will probably provide the strongest clue towards a model of the internal structure of today's students' keyboard skills. However, we will report on all three methodological approaches in order to estimate the impact of different tasks on typing behavior compared to the impact of individual typing strategies.

Correlations

Correlations between identical variables across tasks are shown in Table 10. From this compilation it becomes obvious that typing speed in its traditional sense is the expected most stable characteristic of the participants' typing skill across the various tasks. When compared to one another, fast (or slow, respectively) typers in one task are also fast (or slow, respectively) in other tasks. This is reflected in the high correlations between keystroke intervals within words. Intervals between keystrokes other than within words are also significantly correlated, but to a lower extent, indicating that differences of individual typing skills and strategies do not fully account for the observed variance; task characteristics may also play a role. The proportion of pauses compared to execution time in writing may also be a rather stable pattern of a writer; because of the fact that in the first task there was almost no variance on this variable, the two correlations with the first task necessarily remain low. Another candidate for a continuous typing pattern of individuals can be seen in the number of typing errors that remain uncorrected in the final next. Because there have been almost no typographic errors in the first task's texts, the small correlations with task 1 are not decisive compared to the relatively high correlation between tasks 2 and 3. Deleting appears to be different with copying tasks compared to a generating task.

Table 10. Correlations between variables across tasks (task 1: copying from memory; task 2: copying from text; task 3: generating from memory) (* and ** indicate significance below .05 and .01)

Variable	Task 1 – task 2	Task 1 – task 3	Task 2 – task 3
N keystrokes total	–.073	.126	.077
N deletions	.468**	.023	.126
N cursor movements	–.132	.360*	.079
Time on task (sec)	.666**	.282	.291
Transition time within words (sec)	.910**	.940**	.959**
Transition time other (sec)	.540**	.451**	.407*
Relative pause time (%)	.252	.271	.489**
N errors in final text	.248	.408*	.574**
N of characters in final text	–.120	–.173	–.024
Keyboard efficiency (%)	–.034	.186	–.062

Comparisons of means

The values of some of the considered variables do not meaningfully compare across tasks, because these vary with respect to text lengths. For the variables with proportional or relative values, however – namely, transition time within words, transition time other, relative pause time, and keyboard efficiency – comparisons are reasonable which are shown in Table 11 (repeated measurement ANOVA).

It can be seen that different tasks lead to different values of typing behavior variables. All pairwise contrasts are statistically significant except for transition time other copying from text versus generating from memory and keyboard efficiency copying from memory versus copying from text. Writing down formulations already available in memory proceeds fast and does not need pauses. Because copying from memory involved repetitions of the same wording, little keyboard activities other than the mere keypresses of (correct) letters were necessary which leads to high keyboard efficiency. Interestingly, copying a longer text reduces typing speed even for letters within words, and this even more than the text generation task. Reading the passages to be copied and the related eye-hand coordination apparently require particular skills beyond keyboard mastery. The involved attentional moves also contribute to a higher proportion of pauses above two seconds. It seems that within the typical typing skills of university students eye-hand coordination is more difficult than brain-hand coordination.

Table 11. Comparisons of means (standard errors in parentheses) across tasks for selected variables (df = 2)

Variable	Copying from memory	Copying from text	Generating from memory	F	MSE	Sign.
Transition time words (sec)	.167 (.006)	.194 (.006)	.183 (.007)	64.31	.00008	p < .001
Transition time other (sec)	.295 (.011)	.458 (.026)	.411 (.148)	23.09	.010	p < .001
Relative pause time (%)	2.01 (.41)	12.15 (1.38	20.11 (1.47)	84.12	.003	p < .001
Keyboard efficiency (%)	89.54 (1.56)	86.02 (1.96)	78.98 (2.64)	6.74	.014	p < .01

Keyboard efficiency only moderately decreases, however, because copying needs correction, not revision. Eventually, when generating text from memory, the amount of pauses increases, probably due to planning and information retrieval. Keyboard efficiency decreases as not only correction, but also revision may become necessary, both leading to keyboard activities beyond the generation of letters, spaces, and punctuation. Note that these differences between the three kinds of tasks hold for the typing skills of university students. Professional typists would show different patterns; in particular, it is expected that they would have the same typing characteristics whether they copy from memory or from an unknown text.

Factor Analysis

When a factor analysis converges in a certain factorial structure on which the input variables have different loads, factor scores can be computed which express the value of participants on the extracted and rotated components. Within a task, the factors are orthogonal to one another, yielding zero correlations. But a comparison of factor scores across tasks can show whether participants score similarly on factors that received similar or corresponding interpretations. Since for all three tasks three factors each were extracted, there is a total of nine factors, the scores of which can be correlated. From the 36 resulting correlations ((81 – 9)/2), 9 are zero by necessity.

From the 27 remaining empirically meaningful coefficients, only three pairs of factors are statistically significantly correlated on a p < .01 level, namely the three factors that were interpreted as representing typing speed (.822, .684, and .687). Although for each task, there was a clear activity/efficiency factor independent of typing speed, the clusters of typing behavior variables that fit together to form the respective patterns of keyboard activity appear to differ from task to task. Moreover, it turns out that the length of the text composed in the third writing assignment (Factor 3 of Task 3: generating from memory) has nothing in common with any other cluster of typing behavior.

5. General discussion

This research started from the assumption that today's university students' typing skills are not that of professional typists, but that students have individually different, though effective and fluent ways for successful keyboard operation. Because with keyboard writing, speed, accuracy, and navigation skills can possibly mutually compensate, we studied whether there are patterns of overall keyboard behavior and whether such patterns are stable across tasks. The given tasks varied with respect to complexity and the processes involved: from the multiple repetition of a well-known song line over the copying of text to the generation of a route description.

On a most general level, it was confirmed that university students who can be considered experienced and successful with respect to their educational skills, including the use of computer keyboards, do not employ typing behaviors like professional typists who master a ten-finger touch-typing method with the highest perfection and without any need of visual keyboard control. Rather their speed and precision are clearly worse than with professional typists, as studied in traditional typing skill research. On the other side, 'typical' university students are definitely skilled keyboard users, with average interstroke intervals within words up to 170 milliseconds. This is enormously more fluent than unpractised beginners.

For each of the three tasks, typing skill comprises more than mastering – or not – a touch-typing method. At least two independent sources of variation have been found in all three tasks' overall patterns of keyboard operation. First, students differ with respect to the amount of keyboard activity beyond the mere typing of the required characters, i.e. deleting mistyped characters, or moving the cursor back and forth for correction or revision. We defined the measure of keyboard efficiency to reduce this source of typing variability to the common denominator – the proportion of characters in the final text with respect to the number of keystrokes needed to produce them. The different strategies of either continuously monitoring the written traces on the screen and correcting them immediately if necessary or first working on the entire writing assignment and then editing and correcting may also affect keyboard efficiency. Compared to Hayes and Chenoweth (2006), who report proportions of what they call "wasted keystrokes", between 8 and 10 per cent for a copy task (i. e. 90 to 92 per cent keyboard efficiency), our participants show smaller keyboard efficiency for the tasks copying from text (86 per cent) and generating from text (79 per cent). Again, this points to the fact that typing patterns other than mere intra-word speed may not become visible in most typing research because its participants display highly selected proficiency levels rather than typical typing behavior. Second, students differ with respect to their basic typing speed. Within the tasks, these two facets of typing skill are mutually independent. Faster as well as slower typists can have higher or lower keyboard efficiency.

Across tasks, typing speed turned out to be the most stable characteristic of a keyboard user. Elsewhere (Grabowski, Blabusch & Lorenz, 2006), we reported for copy tasks that typing speed even correlates with handwriting speed by .41, indicating some cross-modal writing speed ability in individuals. However, the influences of the respective writing task always add to individual typing preferences or strategies, leading to different absolute values of the respective variables. Different from professional typists, however, high typing speed in university students does not necessarily go hand in hand with high typing precision. Although there are indications towards a separate factor relating to typing precision (few deletes), this factor was not clearly confirmed. Moreover, there are indications of two different aspects of typing correctness: accuracy during the process of typing, and precision of the final text.

With respect to the acquisition of typing skills, it is worth noting that keyboard proficiency in computer use comprises more, or even something different, than touch-typing training. Typing speed certainly rises through sheer practice. But mere touch-typing training would not teach the strategies of typing that allow for high quality and high accuracy texts through nevertheless efficient processes of keyboard operation. Keyboard functions other than letters, punctuation, caps lock and the space bar also need high degrees of automation to avoid interference with high-level processes. For younger school students in the process of developing keyboard operation skills, fluent mastery of navigational means may even be a basic prerequisite of correction and revision processes.

In subsequent studies, we will focus on differences in students' typing behavior that emerge from whether a computer mouse is available or not. For many, particularly younger students, computer use means using game control devices and clicking on buttons on the screen, at best entering names, passwords, and brief chains of information, but refraining from keyboard activities that create more complex texts. Such rudimentary ways of keyboard use may include good, even automated mastery of the location of the various keys, but do not lead to much practice of continuous bi-manual keyboard operation. In particular, navigation within a text may suffer from the absence of the mouse, which in turn may impair keyboard efficiency. Whatever typing behavior patterns will eventually be found for today's students, they will certainly be quite different from the traditional touch-typing proficency of typists.

References

Alamargot, D. & Chanquoy, L. (2001). *Through the models of writing*. Dordrecht: Kluwer. doi: 10.1007/978-94-010-0804-4

Alves, R. A., Castro, S. L., de Sousa, L. & Strömqvist, S. (2007). Influence of typing skills on pause-execution cycles in written composition. In M. Torrance, L. van Waes & D. Galbraith (eds.), *Writing and cognition: Research and applications* (pp. 55–65). Amsterdam: Elsevier.

Andersson, B. et al. (2006). Combining keystroke logging with eye tracking. In L. van Waes, M. Leijten & C. Neuwirth (eds.), *Writing and digital media* (pp. 166–172). Oxford: Elsevier.

Bourdin, B. & Fayol, M. (1994). Is written language production more difficult than oral language production? A working memory approach. *International Journal of Psychology*, *29*, 591–620. doi: 10.1080/00207599408248175

Bourdin, B. & Fayol, M. (2002). Even in adults, written production is still more costly than oral production. *International Journal of Psychology*, *37*, 219–227. doi: 10.1080/00207590244000070

Butsch, R. L. C. (1932). Eye movements and the eye-hand-span in typewriting. *Journal of Educational Psychology*, *23*, 104–121. doi: 10.1037/h0073463

Coover, J. E. (1923). A method of teaching typewriting based upon a psychological analysis of expert typing. *National Education Association*, *61*, 561–567.

Denis, M., Daniel, M. P., Fontaine, S. & Pazzaglia, F. (2001). Language, spatial cognition, and navigation. In M. Denis, R. H. Logie, C. Cornoldi, M. de Vega & J. Engelkamp (eds.), *Imagery, language and visuo-spatial thinking* (pp. 137–160). Hove: Psychology Press.

Fayol, M. (1999). From on-line management problems to strategies in written composition. In M. Torrance & G. Jeffery (eds.), *The cognitive demands of writing* (pp. 13–23). Amsterdam: Amsterdam University Press.

Gentner, D. R. (1983). The acquisition of typing skill. *Acta Psychologica*, *54*, 233–248. doi : 10.1016/0001-6918(83)90037-9

Gentner, D. R., Larochelle, S. & Grudin, J. (1988). Lexical, sublexical, and peripheral effects in skilled typewriting. *Cognitive Psychology*, *20*, 524–548. Doi: 10.1016/0010-0285(88)90015-1

Grabowski (forthcoming). *Speaking, writing, and memory span in children: Output modality affects cognitive performance*. Manuscript, submitted for publication.

Grabowski, J. (2007). *Typing and handwriting performance of university students*. Paper, presented at the 4th Conference of the European Association for the Teaching of Academic Writing (EATAW), Bochum (D).

Grabowski, J., Blabusch, C. & Lorenz, T. (2006). *Performing a copy task: Processes and strategies in the keyboard typing and handwriting of university students and schoolchildren*. Paper, presented at the 10th Conference of the EARLI Special Interest Group on Writing, Antwerp (B).

Grabowski, J., Blabusch, C. & Lorenz, Th. (2007). Welche Schreibkompetenz? – Handschrift und Tastatur in der Hauptschule. [Which writing competence? Handwriting and keyboard in secondary modern school.] In M. Becker-Mrotzek & K. Schindler (eds.), *Texte schreiben* (pp. 41–61). Kölner Beiträge zur Sprachdidaktik, 5. Köln: Gilles & Francke.

Hayes, J. R. & Chenoweth, N. A. (2006). Is working memory involved in the transcribing and editing of texts? *Written Communication*, *23*, 135–149. doi: 10.1177/0741088306286283

Inhoff, A. W. (1991). Word frequency during copytyping. *Journal of Experimental Psychology: Human Perception and Performance*, *17*, 478–487. doi: 10.1037/0096-1523.17.2.478

Inhoff, A. W. & Gordon, A. M. (1997). Eye movements and eye-hand coordination during typing. *Current Ddirections in Psychological Science*, *6*, 153–157. doi:10.1111/1467-8721.ep10772929

Inhoff, A. W. & Wang, J. (1992). Encoding of text, manual movement planning, and eye-hand coordination during copytyping. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 437–448. doi: 10.1037/0096-1523.18.2.437

Just, M. A. & Carpenter, P. A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review*, *99*, 122–149. doi: 10.1037/0033-295X.99.1.122

Kellogg, R. T. (1994). *The psychology of writing*. New York: Oxford Univerity Press.

Kellogg, R. T. (2001). Competition for working memory among writing processes. *American Journal of Psychology*, *114*, 175–191. doi: 10.2307/1423513

MacArthur, C. A. (2006). The effects of new technologies on writing and writing processes. In C. A. MacArthur, S. Graham & J. Fitzgerald (eds.), *Handbook of writing research* (pp. 248–262). New York: Guilford Press.

Mayer, M. (1969). *Frog, where are you?* New York: Dial Press.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, *63*, 91–97. doi: 10.1037/h0043158

Nottbusch, G., Weingarten, R. & Sahel, S. (2007). From written word to written sentence production. In M. Torrance, L. van Waes & D. Galbraith (eds.), *Writing and cognition: Research and applications* (pp. 31–53). Amsterdam: Elsevier.

Olive, T. & Kellogg, R. T. (2002). Concurrent activation of high- and low-level production processes in written composition. *Memory and Cognition*, *30*, 594–600. doi: 10.3758/BF03194960

Penney, C. G. & Blackwood, P. A. (1989). Recall mode and recency in immediate serial recall: Computer users beware! *Bulletin of the Psychonomic Society*, *27*, 545–547. doi: 10.3758/BF03334664

Rieger, M. (2004). Automatic keypress activation in skilled typing. *Journal of Experimental Psychology: Human Perception and Performance*, *30*, 555–565. doi: 10.1037/0096-1523.30.3.555

Salthouse, T. A. (1986). Perceptual, cognitive, and motoric aspects of transcription typing. *Psychological Bulletin*, *99*, 303–319. doi: 10.1037/0033-2909.99.3.303

Spelman Miller, K. (2006). Pausing, productivity and the processing of topic in on-line writing. In K. P. H. Sullivan & E. Lindgren (eds.), *Computer keystroke logging and writing* (pp. 131–155). Oxford: Elsevier.

Strömqvist, S., Holmqvist, K., Johansson, V., Karlsson, H. & Wengelin, Á. (2006). What keystroke logging can reveal about writing. In K. P. H. Sullivan & E. Lindgren (eds.), *Computer keystroke logging and writing* (pp. 45–71). Oxford: Elsevier.

Sullivan, K. P. H. & Lindgren,. E. (eds.) (2006a). *Computer keystroke logging and writing*. Oxford: Elsevier.

Sullivan, K. P. H. & Lindgren, E. (2006b). Digital tools for the recording, the logging and the analysis of writing processes. In L. van Waes, M. Lijten & C. Neuwirth (eds.), *Writing and digital media* (pp. 153–186). Oxford: Elsevier. doi: 10.1163/9781849508209_014

Torrance, M. & Galbraith, D. (eds.). (1999). *Knowing what to write*. Amsterdam: Amsterdam University Press. doi: 10.5117/9789053563076

Torrance, M. & Galbraith, D. (2006). The processing demands of writing. In C. A. MacArthur, S. Graham & J. Fitzgerald (eds.), *Handbook of writing research* (pp. 67–80). New York: Guilford Press.

Weingarten, R., Nottbusch, G. & Will, U. (2004). Morphemes, syllables and graphemes in written word production. In T. Pechmann & C. Habel (eds.), *Multidisciplinary approaches to speech production* (pp. 529–572). Berlin: de Gruyter.

Wengelin, Á. (2006). Examining pauses in writing: Theory, methods and empirical data. In K. P. H. Sullivan & E. Lindgren (eds.), *Computer keystroke logging and writing* (pp. 107–130). Oxford: Elsevier.

Acknowledgements

I am grateful to Hanna Kühne and Annika Keller, students from Heidelberg University of Education, who carried out the experiment and prepared data for subsequent analyses. Christian Weinzierl has been on call with respect to the technical resources during experimentation. Moreover, I have to thank him and Markus Schmitt for fruitful discussions, and Thorsten Lorenz for his friendly cooperation which taught me a lot about writing media. The conducting of this experiment was supported by a grant from Forschungsverbund Hauptschule Baden-Württemberg.