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# On the Acquisition of Typing Skills Without Formal Training by School-Aged Children

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### **Competing interest**

The authors have no competing interest to declare.

### **Authors' contributions**

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Data curation: Svetlana Pinet

Formal analysis: Svetlana Pinet

Funding acquisition: F.-Xavier Alario, Marieke Longcamp

Investigation: Christelle Zielinski, Marieke Longcamp

Methodology: F.-Xavier Alario, Marieke Longcamp, Christelle Zielinski

Project administration: F.-Xavier Alario, Marieke Longcamp

Resources: F.-Xavier Alario, Marieke Longcamp, Svetlana Pinet

Software: Christelle Zielinski, Svetlana Pinet

Supervision: F.-Xavier Alario, Marieke Longcamp

Validation: Svetlana Pinet

Visualization: Svetlana Pinet

Writing – original draft: Svetlana Pinet

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# On the Acquisition of Typing Skills Without Formal Training by School-Aged Children

## Abstract

Typing is not formally taught at school in most European countries, despite digital activities being increasingly prevalent in children's curricular requirements. Typing skills presumably emerge from informal practice, modulated by the availability and use of tools at school or at home. The cognitive processes leading to typing skill acquisition in children have not been described in any detail. To characterize the acquisition of typing skills across school years, we collected data from children schooled in grades 4 to 9 using a questionnaire on typing practice and various chronometric tasks. In our cross-sectional sample of 131 children, the time spent typing or handwriting was stable over grades, but the self-reported number of fingers used for typing increased with grade. The chronometric tasks required typing single letters (alphabet), single words (word copying and picture naming), and sentences (copying and composition). Across tasks, typing speed increased and keypress duration variability decreased with grade. Typing performance for single keystrokes and for words was modulated by a combination of psycholinguistic factors and physical constraints, whose influence decreased with grade, pointing to the ongoing –yet incomplete– organization of the typing process. Text composition performance was highly correlated with performance in text copying. These findings are interpreted with reference to previous results in adults and models of typing expertise. Quantifying the evolution of typing performance opens avenues to fully understand the cognitive processes underlying the acquisition of typing skills and the generation of typing behavior.

Keywords: spelling, motor, expertise, keystroke, psycholinguistic

1 While children's exposure to screens is widely discussed, there is less  
2 consideration of their use of keyboards. This is despite the high and ever-increasing  
3 prevalence of keyboards in a variety of contexts in industrialized societies. In most  
4 European countries, there is very little formal typing instruction. Children's typing  
5 skills thus presumably emerge from uninstructed practice, modulated by the  
6 availability and use of tools at school or at home.  
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10 Typing performance in children has often been assessed by measuring the  
11 quality (i.e., structure, complexity, and correctness) and fluidity (i.e., number of  
12 words) of texts produced with keyboards, in order to understand what factors affect  
13 text composition. Text quality is linked to so-called transcription skills, made of  
14 spelling skills and low-level motor aspects of letter typing (Beers et al., 2017;  
15 Berninger et al., 2009; Gahshan-Haddad & Weintraub, 2023; Graham, 2018;  
16 Jiménez & Hernández-Cabrera, 2019; Malpique et al., 2024). Such interpretations  
17 are consistent with the idea that the acquisition of low-level "transcription" writing  
18 skills allows freeing up cognitive resources to be devoted for higher compositional  
19 processes such as idea formulation (Barnett & Stuart, 2024; Graham, 2018;  
20 McCutchen, 1996).  
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31 Still, the mechanisms underlying the acquisition of typing skills have not been  
32 explicitly described (but see Jiménez et al., 2017 in first- to third-grade children).  
33 Moreover, an account of the mental information processes that generate children's  
34 typing behavior is missing, as pointed out by Barnett and Stuart (2024). Such  
35 accounts have proven their value to understand the factors underlying typing skills in  
36 adults (Pinet et al., 2022) and handwriting skills in both adults and children (Kandel  
37 et al., 2011; Kandel & Perret, 2015).  
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45 The landmark behavior signaling typing expertise is the ability to strike keys  
46 quickly and accurately on a computer keyboard (Ericsson et al., 1993; Larochelle,  
47 1983; Logan, 2018; Rumelhart & Norman, 1982). Nowadays, the adult population  
48 shows a wide range of such expertise (Dhakal et al., 2018; Feit et al., 2016). Typing  
49 performance has been linked to the amount of practice, independently of formal  
50 training or deliberate practice (Keith & Ericsson, 2007), suggesting that expert-like  
51 behavior in typing could be acquired with practice alone (Pinet et al., 2022).  
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58 Adult expert typing constitutes an automatized behavior acquired through  
59 practice (Logan, 2018). Automaticity refers to a behavior that is "fast, effortless,  
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1 autonomous, stereotypic, [and] unavailable to conscious awareness” (Logan, 1988).  
2 Expert typing has been theorized as a hierarchical skill combining language  
3 processing and keystroke execution, each under the control of a specific processing  
4 loop (Logan & Crump, 2011; see left panel of Figure 1). The outer loop is in charge  
5 of assembling words into sentences, while the intricacies of keystroke execution  
6 (moving and coordinating fingers) are controlled by the inner loop. The inner loop is  
7 encapsulated within the outer loop, and each loop functions independently from the  
8 other, for example processing specific feedback: from the fingers/keyboard or from  
9 the screen, for the inner and outer loops respectively (Logan, 1988). The  
10 development of two independent and encapsulated loops is considered a sign of  
11 automaticity (Logan, 2018; Logan & Crump, 2011). While previous studies have  
12 focused on the differences in adult participants between a novice state to such an  
13 expert state where the two loops are organized (Laroche, 1983; Pinet et al., 2022),  
14 a thorough characterization of typing skill acquisition in children is still missing.  
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27 Children’s developmental trajectory is likely to prompt important differences  
28 between their typing behavior and adult typing skills. Orthographic knowledge  
29 underlying reading and writing is extensively trained from 5-6 years old onward, and  
30 takes several years to be fully acquired, in particular in deep orthographic systems  
31 such as English or French (Treiman, 2017). The development of literacy could thus  
32 impact the acquisition of typing skills (Gahshan-Haddad & Weintraub, 2023). In  
33 addition, motor development is ongoing throughout childhood and adolescence,  
34 meaning that motor skills are not yet stabilized like they are in adults (Kutzt-  
35 Buschbeck et al., 1998; Takahashi et al., 2003). As a comparison, handwriting is  
36 considered fully mature only at adolescence (Zesiger, 1992). Ongoing spelling  
37 acquisition and motor development may conceivably create a specific pattern of  
38 typing skill acquisition in children, distinct from adults’ training trajectories  
39 (Laroche, 1983).  
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53 The different processes underlying the two loops of typing can be assessed  
54 by specific tasks of increasing complexity (Barnett & Stuart, 2024; Pinet et al., 2022;  
55 Figure 1). Starting at the lowest level of pressing keys (i.e., the inner loop), keystroke  
56 execution requires mentally selecting a letter, reaching the appropriate key location,  
57 and effectively depressing the key. Moving up in the language hierarchy (i.e., the  
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outer loop), letters need to be assembled into syllables, words, and sentences. Word typing recruits psycholinguistic processes, such as lexical selection and spelling retrieval. Typing sentences further calls for syntactic processing and grammatical encoding. Finally, additional formulation processes, such as generating and organizing thoughts and ideas, are necessary for text composition.

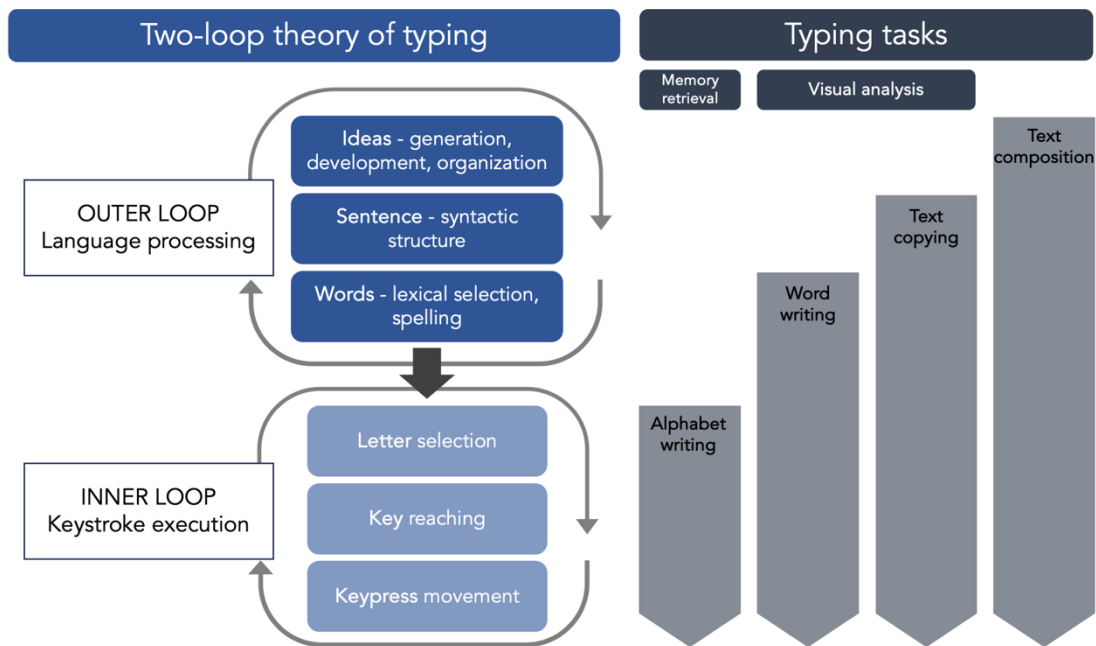


Figure 1: Two-loop theory of the organization of typing processes in experts (left, Logan & Crump, 2011) and typing tasks assessing specific processes of the typing system (right). Additional processes required for each task are indicated in a dark box above. Adapted from Barnett and Stuart, 2024.

## The current study

The goal of this study is to assess the acquisition of typing skills over grades, spanning from the end of primary school to the end of secondary school, using the model depicted in Figure 1. In particular, we aim to describe how the automatization of typing skills in school-aged children develops at different processing levels and in relation with typing habits. Children from Grades 4 to 9 went through several typing tasks to assess their typing skills at the level of keystrokes (alphabet typing), single words (copy and picture naming), and sentences (text copying and composition; Figure 1). Children also completed a questionnaire on their typing habits. We characterized children's performance using different variables: interkeystroke intervals (IKIs, i.e., the time elapsing between successive keystrokes), accuracy, reaction time (time up to the first keystroke), and keypress durations.

## Method

### Participants and recruitment

The sample comprised 131 children and adolescents enrolled in primary (4th and 5th grades) and secondary school (6th, 7th, 8th and 9th grades). There were no specific exclusion criteria. Demographic characteristics are summarized in Table 1. Participants were recruited via a link e-mailed to the staff of Aix-Marseille University so parents or legal guardians could invite their children to participate. No attempt was made to limit participation to children of university staff, nor to actively extend it beyond this population. A prize draw for a 30€ voucher was organized among participants, with one winner every 30 participants on average. The method used to select winners guaranteed the anonymity of the data. The experiment was approved by Aix-Marseille University ethics committee (approval number 2019-17-01-003). Data was collected online at the end of the school year 2019; the procedure requested that this was done in the presence of the child's parent or legal guardian and under their full responsibility.

Table 1. Demographic information about the sample.

Grade	French grade	N	Handedness			Gender		Age
			left	right	ambidextrous	female	male	
4	"CM1"	25	0	23	2	12	13	9.2
5	"CM2"	28	4	23	1	21	7	10.2
6	"6ème"	26	8	17	1	23	3	11.4
7	"5ème"	21	2	18	1	9	12	12.2
8	"4ème"	16	1	15	0	7	9	13.3
9	"3ème"	15	3	10	2	10	5	14.3

### Tasks and procedure

The experiment was developed using the open-source library *jsPsych* (v4.3, de Leeuw, 2015), which contains predefined methods for managing the experiment's sequence of events and collecting responses. Technical aspects specific to the online measurement of typing, such as the validity of responses and accuracy of timing, have been validated by Pinet et al. (2017). The experiment was run in a browser using JavaScript functions embedded in HTML web pages. The experiment



1 was run by each participant on their own equipment and required using a computer  
2 with a physical keyboard (i.e., not a tablet or phone).

3 We adapted an online test aimed at adults (Pinet et al., 2022) by reducing the  
4 total duration to around 15 minutes, on the assumption that children would be slower  
5 to respond and more prone to distraction. The test comprised five parts (alphabet  
6 transcription, picture naming, word copying, sentence copying, composition writing)  
7 and a questionnaire on writing practice. We designed two versions of the test, one  
8 for secondary school children (who had to complete all five tasks) and one for  
9 primary school children (with reduced text in the sentence-copying task and no  
10 composition task). At the start of the experiment, participants selected their grade to  
11 access the appropriate version of the experiment. To promote the quality of  
12 responses, an answer could only be validated if a certain number of characters were  
13 typed: half of those expected for the alphabet, word copying, and sentence copying  
14 tasks, three characters for picture naming and ten for composition. Answers to all the  
15 questions of the questionnaire at the end of the experiment were mandatory.

16 The different parts were presented in a pseudo-random order. The alphabet  
17 task was always presented first, allowing the participant to identify or remember all  
18 the letters on the keyboard. Next came a word task (either the picture naming or  
19 word copying task) selected randomly across participants, followed by the sentence  
20 copying task and the composition task (if applicable). Finally, participants completed  
21 the other word task that had not yet been presented. As the words used for the two  
22 word tasks were the same, inserting one (or two) intervening task(s) helped  
23 mitigating any anticipatory effect. The order of words and images within each task  
24 was completely random. The order of sentences in the sentence copying task was  
25 kept constant as they formed a short story.

26 All tasks were preceded by an instruction screen describing the nature of the  
27 task, and asking participants to write as quickly and as accurately as possible. Each  
28 task was launched by the participant, when ready, by pressing a key.

### 29 ***Alphabet typing task***

30 The alphabet task is typically used to assess typing speed and accuracy of  
31 individual letters in children (Alstad et al., 2015; Barnett & Stuart, 2024; Malpique et  
32 al., 2024). The participant was instructed to write the alphabet from memory without  
33 adding spaces between the letters. A visual instruction ("Write the alphabet")  
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1 indicated the beginning of the task, and the letters were displayed on the screen as  
2 they were typed. The task ended when the participant pressed the enter key.  
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### 5 ***Picture naming and word copying tasks***

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7 The same 20 words were used for the two tasks. They were selected so that  
8 their linguistic features and the position of letters on the keyboard were  
9 homogeneously distributed (see Appendix 1). Images were taken from Alario and  
10 Ferrand (1999), Bonin et al. (2003), and additional sources, and had a name  
11 agreement of 100% in adults. At each trial, a stimulus (image or word) was  
12 presented at the top of the screen; letters were displayed on the screen right below  
13 the stimulus as they were being typed. Participants pressed the enter key to move  
14 on to the next trial.  
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### 23 ***Sentence copying task***

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25 We generated a short text of 4 sentences containing solely words with  
26 unaccented letters (see Appendix 2). The sentences appeared one-by-one on the  
27 screen, and participants had to copy them. Their response appeared underneath the  
28 presented sentence, and they had to press the enter key to move on to the next  
29 sentence. For primary school children, only the first two sentences were presented.  
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### 36 ***Composition task***

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38 The composition task was presented immediately following sentence copying  
39 task. Children were required to write a continuation of the text copied in the previous  
40 task. The instruction screen specified that the text could be written without capital  
41 letters, accents or punctuation, and that there was no need to correct errors. The  
42 four sentences from the previous task were displayed on the screen again, and the  
43 text produced appeared in a box below. The participant had a maximum of five  
44 minutes to complete the task. A "validate my story" button displayed on the screen  
45 could be used to end the task earlier.  
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### 54 ***Questionnaire***

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56 After the writing tasks, an online form was used to collect anonymous  
57 information about the participant: age in years, mother tongue, typing habits (daily  
58 use of a computer and smartphone, daily time typing, number of years of practice,  
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1 habits at school and formal training, number of fingers used and frequency of looks  
2 to the keyboard) and handwriting habits (dominant hand, daily time spent  
3 handwriting).  
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## 7 **Data analysis**

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9 For each experimental task, we recorded the identity of the letters typed, the  
10 timestamp of each keystroke, and the duration of each key press. For each item of  
11 the questionnaire, we collected a single response chosen among pre-specified  
12 options or typed in a text box.  
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16 All statistical procedures were performed using R software (version 4.0.5, R  
17 Core Team, 2021). We performed linear regressions, generalized linear regressions,  
18 and linear mixed effect models (package *lmerTest*, Kuznetsova et al., 2017)  
19 depending on the variable. In all the analysis, grade was entered as a numerical  
20 linear predictor.  
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25 Data and analysis scripts can be accessed at the following OSF repository  
26 (anonymous view-only link for peer-review):  
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28 [https://osf.io/y2g59/?view\\_only=1ac12e3ce6e34a018a05677cdae597a4](https://osf.io/y2g59/?view_only=1ac12e3ce6e34a018a05677cdae597a4)  
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## 32 **Typing habits**

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34 The effect of grade was estimated on the different typing habits variables  
35 collected from the questionnaire: daily use of a computer, daily time typing, habits at  
36 school, formal training, number of fingers used and frequency of looks to the  
37 keyboard. We also tested for the effect of grade on handwriting habits (daily time  
38 handwriting), for comparison.  
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## 45 **Alphabet typing task**

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47 The time interval between keystrokes (IKI) was computed by subtraction  
48 between the time-stamps of successive keystrokes. Key press duration was readily  
49 available in the data log. Only correct bigrams (i.e., two consecutive correct letters)  
50 were included in the analysis.  
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54 Mean and standard deviation of key press durations were computed per  
55 participant. For the analysis of IKI, grade, letter frequency (log-transformed) and  
56 distance between keys were entered as fixed effects, as well as the interaction of  
57 grade with the other two predictors. Only participant, not letter, was included as a  
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1 random intercept, since each inter-letter interval was typed only once by each  
2 participant. For the additional analysis gauging automatization, we ran a simple  
3 model including only one predictor (either letter frequency or distance between  
4 keys), both as fixed effect and by-participant random effect, in addition to by-  
5 participant random intercept. Then, we tested for the correlation of the effect  
6 estimated by the model for each participant and the number of fingers participants  
7 reported using.  
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### 13 ***Single word typing tasks***

14 For the picture naming and word copying tasks, the following dependent  
15 variables were computed: response time (RT), defined for each trial as the time  
16 between the presentation of the stimulus and the striking of the first keystroke, and  
17 interkeystroke interval (IKI), defined as the time between two successive keystrokes.  
18 Only correct trials without backspace were included in the analysis. Extreme values  
19 (IKI over 5s, RT over 10s and mean IKI over 2.5s) were considered to be outliers  
20 and were removed from the dataset.  
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29 For IKI, the fixed effects were: task, letter frequency (log-transformed),  
30 distance between keys, bigram frequency (log-transformed), position of the interval  
31 within word, whether the interval constituted a syllable boundary, whether it was part  
32 of a complex grapheme, age of acquisition and word length. In addition, we included  
33 grade and its interaction with all the aforementioned predictors. Random intercepts  
34 were estimated for participant and letter. Categorical predictors (task, syllable  
35 boundary, and complex grapheme) were sum-coded. The RT analysis included the  
36 same fixed effects as for IKIs, but the predictors estimated at the letter or bigram  
37 level (letter frequency, bigram frequency, distance between keys, and complex  
38 graphemes) were averaged over the whole word; syllable boundary and position  
39 were not included. Random intercepts for participant and word were included.  
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### 51 ***Sentence copying task***

52 Typing speed was defined as the number of 5-character “words” (total number  
53 of keystrokes normalized by 5; Pinet et al., 2022) divided by the time between the  
54 first and last keystrokes. Errors were computed with the library *TraMineR* (v2.2-3;  
55 Gabadinho et al., 2011) that yielded deviations from the target sentence in number of  
56 insertions, deletions, and substitutions. The error rate was defined as the number of  
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1 errors divided by the number of characters in the target sentence, and accuracy was  
2 computed as 1 minus the error rate.

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4 Typing speed and accuracy were averaged per participant over sentences (2  
5 sentences for primary school children, 4 for secondary school children). The effect of  
6 grade on each variable was tested with linear regressions. Linear regressions were  
7 also run to test for the effect of typing habits (keyboard use, number of fingers on  
8 typing speed, daily typing time, years of practice) on mean typing speed. Typing  
9 habits at school, formal training, and frequency of looks to the keyboard were not  
10 included because their distribution was too imbalanced in our sample.  
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### 17 **Composition task**

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19 Similar to the sentence copying task, the number of “words” (5-character  
20 normalized) and typing speed were computed. The number of sentences produced  
21 was coded manually. If the child did not use punctuation and/or capital letters, the  
22 number of sentences was approximated based on sentence structure.  
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27 With this task, we aimed to assess inter-dependencies between text  
28 composition and sentence copying, word typing, and alphabet typing tasks. Pairwise  
29 correlations were run between three variables in the composition task (number of  
30 words, typing speed, and number of sentences) and selected variables in other  
31 tasks: mean IKI in the alphabet task, mean RT in the word typing task (averaged  
32 over picture naming and word copying), and typing speed in the sentence copying  
33 task. Grade and the number of fingers used (representing typing habits) were also  
34 included in the pairwise correlations. To avoid correlations from being contaminated  
35 by the underlying effect of grade on each variable, we ran separate linear  
36 regressions for each variable with grade as a predictor. Pairwise correlations were  
37 then run on the residuals from these linear regressions, effectively regressing out the  
38 effect of grade.  
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## 51 **Results**

### 52 **Typing habits**

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54 Over our sample, only 16% of children reported having received training in  
55 typing, and 80% reported never using a keyboard to take notes in class. Although  
56 children reported spending an average of 2.5 hours a day on a computer, less than  
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20% of that time was spent typing text, 30min a day on average. The vast majority of our sample (90% of children) spent less than 1h a day typing text.

The average time spent writing text either through typing or handwriting did not vary significantly over grade, typing:  $\beta = -0.033$ ,  $t = -0.62$ ,  $p > .05$ , handwriting:  $\beta = 0.187$ ,  $t = 1.62$ ,  $p > .05$ . Grade also had no significant influence on the likelihood of using of a computer to take notes in class,  $\beta = 0.145$ ,  $z = 1.08$ ,  $p > .05$ , or of using visual guidance (i.e., looking at the keyboard) while typing,  $\beta = -0.20$ ,  $z = -1.13$ ,  $p > .05$ . Still, as grade increased, significantly more children reported using a keyboard at least twice a week,  $\beta = 0.318$ ,  $z = 2.42$ ,  $p = 0.016$ . The number of fingers children reported using for typing also increased with grade,  $\beta = 0.558$ ,  $t = 4.47$ ,  $p < .001$  (Grade 4:  $2.92 \pm 2.1$  fingers; Grade 9:  $5.93 \pm 2.5$  fingers).

In summary, children's daily use of keyboards was fairly limited but increased with grade. This was accompanied by an increase in the numbers of fingers used. Both keyboard usage and the number of fingers used for typing are among the factors previously identified as underlying expertise (Pinet et al., 2022).

## Typing performance

### *Alphabet typing*

Although children were typing from memory all letters of the alphabet in succession, their sequence does not constitute any typing pattern employed during regular typing and can thus be considered as typing isolated keystrokes. Keystroke execution was decomposed as keypress duration, i.e., the time a key is effectively pressed, and interkeystroke interval or IKI, i.e., the time between pressing successive keystrokes.

**Key press duration.** It is well established that motor skill stabilizes across development, which is typically evidenced as a reduction of variability (Kuhtz-Buschbeck et al., 1998; Takahashi et al., 2003). Accordingly, we assessed participants' mean and standard deviation of key press durations through linear regressions. Over grade, there was a significant decrease of key press durations,  $\beta = -4.02$ ,  $t = -2.6$ ,  $p = .009$ , as well as a significant decrease of the variability of key press durations (participants' standard deviation),  $\beta = -2.25$ ,  $t = -3.1$ ,  $p = .003$  (see Figure 2).

**Interkeystroke intervals (IKIs).** IKI significantly decreased over grade, indicating that typing speed increased (see Figure 2). IKI constitutes the time for selecting the next letter to type as well as movement time to reach its location on the keyboard (Logan & Crump, 2011). Letter selection was indexed by letter frequency: more frequent letters should be selected faster. Movement time to reach a key was indexed by the distance from one key to the next: keys that are closer on the keyboard should be typed faster. There were significant effects of letter frequency and distance between keys on IKIs: more frequent letters and those that are closer on the keyboard were typed faster. Both effects significantly interacted with grade, showing a decrease with grade (see Table 2 and Figure 3).

*Table 2. Results of the mixed model analysis for the alphabet typing task.*

	$\beta$	$t$	$p$	(sig.)
(Intercept)	3716.46	15.68	<.001	***
Grade	-525.96	-7.90	<.001	***
Letter frequency (log)	-301.05	-11.15	<.001	***
Distance	128.09	5.98	<.001	***
Letter frequency x Grade	44.27	5.84	<.001	***
Distance x Grade	-17.51	-2.91	0.004	**

Note. \*\* $p < .01$ . \*\*\*  $p < .001$ .

### **Single word typing**

Performance in single word typing was assessed through IKI (time between consecutive keystroke, indexing response execution) and RT (time from stimulus to first keystroke, indexing response retrieval and programming). The production of single words was prompted with two tasks: word copying and picture naming. The order in which tasks were performed (counterbalanced between participants) had no effect on spelling accuracy,  $\beta = 0.56$ ,  $z = 0.97$ ,  $p > .05$ . Therefore, the data were pooled across tasks, including task as a fixed effect in the statistical analysis.

On individual IKIs, we included the same factors (distance, letter frequency) from the analysis of keystroke execution above. In addition, we included bigram frequency and position of the interval within the word, as these variables index typing execution (Pinet et al., 2022). We also considered whether the interval constituted a syllable boundary (Kandel et al., 2009; Pinet et al., 2016), and whether it was part of a complex grapheme, i.e., a phoneme written with more than one letter, an important

factor in spelling (Kandel & Spinelli, 2010). Finally, we included word-related factors: age of acquisition (AoA, predictor of lexical retrieval) and word length.

Overall, IKI significantly decreased with grade (see Figure 2). As was the case for keystroke execution, we observed significant effects of distance and letter frequency. Again, these effects significantly interacted with grade, with a smaller influence in older children. There was no significant effect of bigram frequency, contrary to results in adults (Pinet et al., 2022). IKI was significantly longer if the interval was part of a complex grapheme or a syllable boundary, and was shorter as the length of the word increased. We also observed a significant effect of AoA, with IKI of later acquired words being longer. These significant main effects had significant interactions with grade, such that their magnitude decreased with grade (see Figure 3).

Table 3. Results of the mixed model analysis for individual IKI in the word typing tasks.

	$\beta$	$t$	$p$	(sig)
(Intercept)	2659.8	9.17	<.001	***
Task	-1.82	-0.35	0.73	
Grade	-364.4	-11.6	<.001	***
Letter frequency (log)	-245.2	-7.24	<.001	***
Distance	51.9	19.6	<.001	***
Bigram frequency (log)	8.90	1.41	0.16	
Position within the word	-5.44	-1.23	0.22	
Syllable boundary	247.2	12.9	<.001	***
Complex Grapheme	111.3	7.61	<.001	***
Age of Acquisition	285.7	16.8	<.001	***
Length	-40.3	-5.46	<.001	***
Letter frequency x Grade	34.5	10.4	<.001	***
Distance x Grade	-8.72	-12.2	<.001	***
Bigram frequency x Grade	-1.34	-0.79	0.43	
Position x Grade	-1.54	-1.26	0.21	
Syllable boundary x Grade	-51.0	-10.6	<.001	***
Complex Grapheme x Grade	-24.8	-6.30	<.001	***
Age of Acquisition x Grade	-64.4	-13.8	<.001	***
Length x Grade	12.4	6.13	<.001	***

Note. \*\*\*  $p < .001$ .

The analysis of RT included the same fixed effects as for IKIs, with letter and bigram frequency, distance between keys, and complex graphemes averaged over



the whole word. Overall, RT significantly decreased over grade (see Figure 2). Moreover, there were significant main effects of task and AoA, with lower RT for word copying than picture naming, and for early than late acquired words. None of the other variables had a significant main effect. There was a significant interaction between AoA and grade: the effect of AoA was lower with increasing grade. Despite the absence of a main effect, there was a significant interaction of mean distance with grade: younger children had faster RT for words that had overall lower distance between keys.

Table 4. Results of the mixed model analysis for RT in the word typing tasks.

	$\beta$	$t$	$p$	(sig)
(Intercept)	8602.0	2.97	0.008	**
Task	473.4	20.4	<.001	***
Grade	-1101.9	-3.07	0.002	**
Mean letter frequency	-716.0	-1.84	0.083	
Mean distance	61.8	1.56	0.14	
Mean bigram frequency	-127.3	-0.726	0.48	
Complex grapheme	-6.52	-0.032	0.97	
Age of acquisition	517.8	2.84	0.011	*
Length	12.9	0.187	0.85	
Mean letter frequency x Grade	82.4	1.72	0.086	
Mean distance x Grade	-11.2	-2.28	0.023	*
Mean bigram frequency x Grade	30.8	1.44	0.15	
Complex grapheme x Grade	7.51	0.297	0.77	
Age of acquisition x Grade	-85.8	-3.84	<.001	***
Length x Grade	9.67	1.14	0.26	

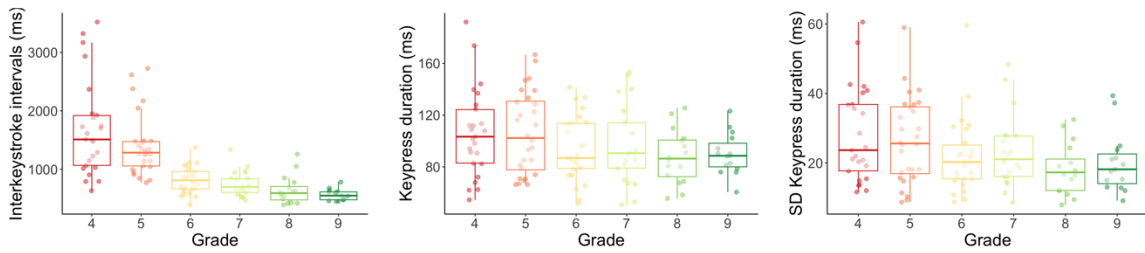
Note. \* $p < .05$ . \*\* $p < .01$ . \*\*\* $p < .001$ .

### Sentence copying

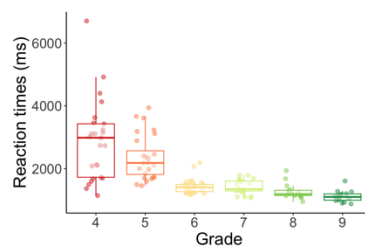
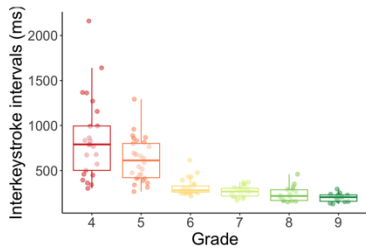
In sentence copying, typing speed significantly increased with grade, but accuracy did not: typing speed:  $\beta = 7.09$ ,  $t = 15.9$ ,  $p < .001$ , accuracy:  $\beta = 0.44$ ,  $t = 1.31$ ,  $p < .05$  (see Figure 2). Further analysis showed that keyboard use (less vs. more than twice a week) was associated with an increase of text copying speed,  $\beta = 9.3$ ,  $t = 3.5$ ,  $p < .001$ . Within regular keyboard users, there was a significant effect of number of fingers on typing speed,  $\beta = 2.0$ ,  $t = 4.3$ ,  $p < .001$ , but there was no significant effect of daily typing time,  $\beta = -0.09$ ,  $t = -0.06$ ,  $p = .95$ , nor of years of practice,  $\beta = .91$ ,  $t = 1.46$ ,  $p = .15$ .

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**a Alphabet task**



**b Word task**



**c Sentence task**

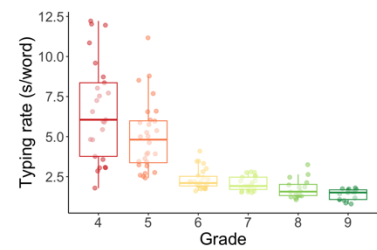
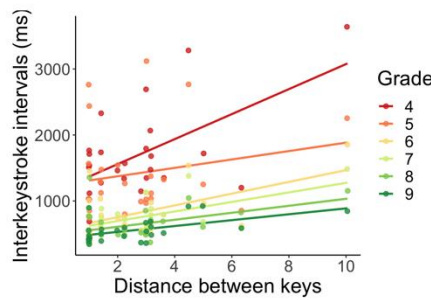
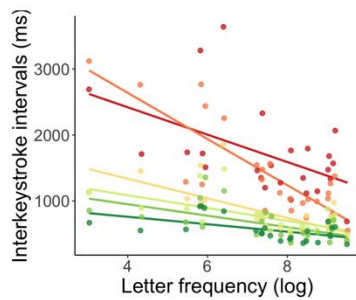


Figure 2. Trajectory of typing performance over grades in (a) alphabet, (b) word, and (c) sentence tasks.

**a Alphabet task**



**b Word task**

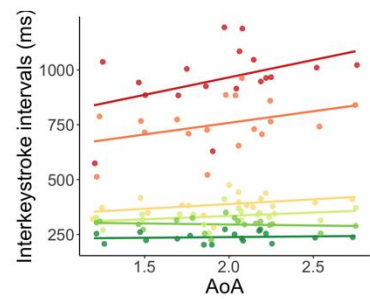
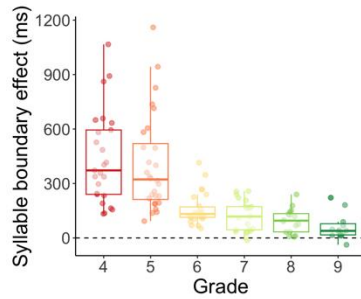
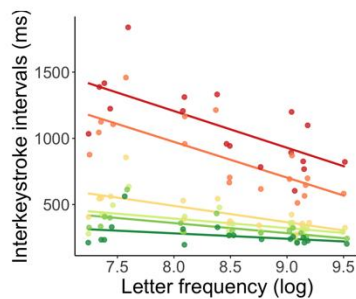


Figure 3. Interactions with grade in the alphabet and word typing tasks. **a.** Interactions of letter frequency (left) and distance between keys (right) with grade on individual IKIs in the alphabet task. **b.** Interactions of age of acquisition (left), syllable boundary (middle), and letter frequency (right) with grade on individual IKIs in the word task.

## ***Automatization of typing behavior***

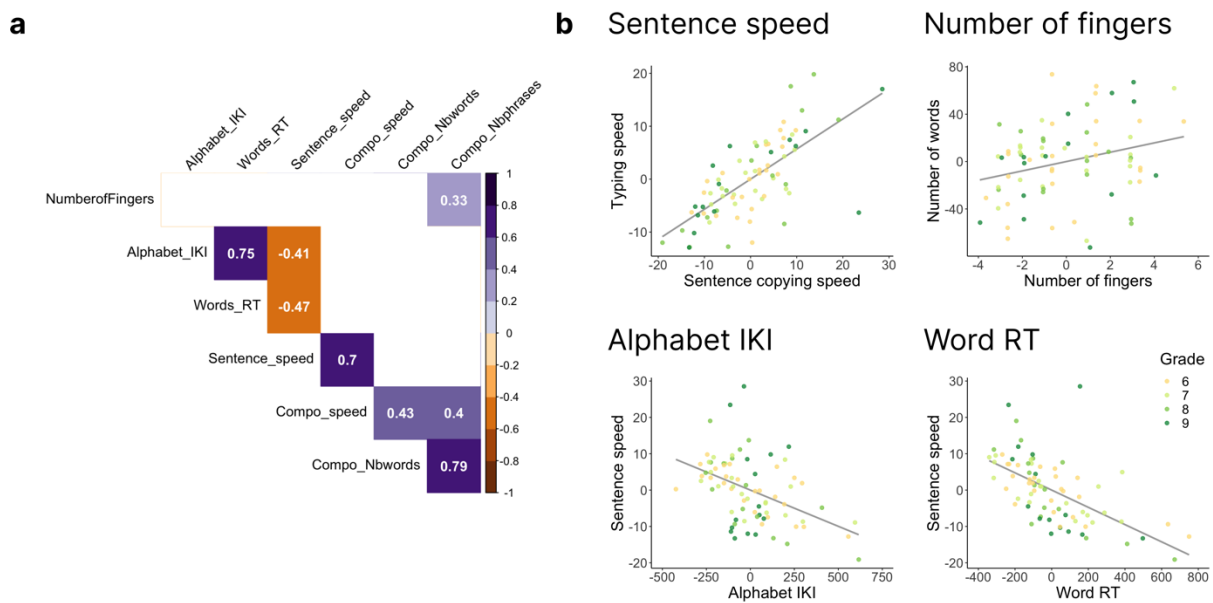
In both alphabet and word typing tasks, the experimental effects significantly interacted and decreased with grade, which could be a reflection of the acquisition of typing expertise. However, interactions with grade could also reflect a generic improvement of performance as opposed to a specific improvement in typing expertise. The speeding up of performance (shorter reaction times and IKIs) associated with grade might simply leave less room for experimental effects to develop, which could result in the interactions observed (e.g., Faust et al., 1999). We tested more directly whether the evolution of a specific index of typing expertise, the number of fingers used for typing (Pinet et al., 2022), was associated with the observed interactions. We focused our analysis on keystroke execution, here indexed by the alphabet task, since it constitutes the level at which typing automaticity has been theorized through the development of the inner loop (Logan & Crump, 2011; see Figure 1).

We ran a mixed model analysis on IKIs in the alphabet task with distance as a predictor including both by-participant random slope and intercept. Including random slopes allows estimating the effect of distance per participant. This individual effect of distance was significantly correlated (negatively) with the number of fingers used for typing,  $R = -.25$ ,  $t = -3.02$ ,  $p = .003$ , such that the more fingers the child reported using, the smaller the individual effect of distance between keys. We followed the same procedure for letter frequency. There was a significant positive correlation between the individual effect of letter frequency and the number of fingers used for typing,  $R = 0.33$ ,  $t = 3.9$ ,  $p < .001$ , such that the more fingers the child reported using, the smaller the individual effect of letter frequency. This analysis argues in favor of a specific development of automatization with grade, indexed by the increase in the number of fingers used for typing, that presumably contributes to the observed interactions with grade over and above the generic improvement of performance.

## **Text production**

Taking a wider perspective on the typing process, text composition encompasses all the processes described above (keystroke, word, and sentence typing; see Figure 1) along with formulation processes that are absent when copying

sentences. To assess inter-dependencies between text composition and the tasks described previously, we ran cross-correlations between performance in the composition task (typing speed, total number of words produced, number of sentences) and performance in the alphabet, word, and sentence tasks, as well as typing habits (number of fingers used) and grade (see Figures 4 and 5). The effect of grade had been previously regressed out of each variable. Typing speed during composition was strongly correlated with sentence copying speed,  $R = 0.70$ ,  $t = 8.5$ ,  $p < .001$ . We observed significant correlations of sentence copying speed with alphabet IKI,  $R = -0.41$ ,  $t = -3.88$ ,  $p < .001$ , and with word retrieval RT,  $R = -0.47$ ,  $t = -4.68$ ,  $p < .001$ . Alphabet IKI and word retrieval RT were themselves significantly correlated,  $R = 0.74$ ,  $t = 9.80$ ,  $p < .001$ . Moreover, the number of fingers children reported using for typing was correlated with the total number of sentences produced,  $R = 0.33$ ,  $t = 3.02$ ,  $p = .003$ .



**Figure 4. a.** Correlation matrix between grade, number of fingers used, and performance in each task. Only significant correlations ( $p > .01$ ) are shown. **b.** Performance in the composition task (speed and number of words; upper row) is significantly correlated with performance in the sentence copying task and with typing habits (number of fingers used). Performance in the sentence copying task (lower row) is significantly correlated with performance in the alphabet and single word typing tasks.

## Discussion

In this study we assessed how typing skills evolve in children as a function of grade. In particular, we aimed to describe how the automatization of typing skills develops through tasks targeting different levels of processing: keystroke, word, and sentence.

### Typing performance in school-aged children

Children in our sample had low typing practice, the majority without formal training. Still, keyboard usage and the number of fingers children reported using for typing increased with grade. Both factors have been previously identified as underlying the automatization of typing skills in adults (Pinet et al., 2022) but, to our knowledge, this is the first report of such variables in a child population. This evolution of typing practice over grade goes in the direction expected to favor the acquisition of typing expertise by children.

Correspondingly, a general improvement of typing performance with grade was observed in all tasks (alphabet, word, sentence) and on all variables (IKI, RT, and keypress durations). The trajectory was consistent across tasks and variables, with strong improvement and high variability over primary school (Grades 4 and 5), while variability decreased and performance kept improving at a slower pace over secondary school (Grades 6 to 9). As this is one of the first reports evaluating the evolution of typing skills in a child population, it can hardly be related to previous studies. Still, the alphabet typing speeds of Grades 4 and 6 in our sample are consistent with those reported by Berninger et al. (2009). Using tasks spanning multiple processing levels our investigation revealed the improvement in typing performance in school children at the keystroke, word, and sentence levels. Our dataset is freely available to ease comparison with other samples in the future and might also constitute a useful benchmark for clinical practice (Abecassis et al., 2023; Barnett & Stuart, 2024; Berninger et al., 2009; in adults, see Pinet et al., 2022; Van Waes et al., 2021).

### Cognitive processes generating typing behavior in children

On single keystrokes and words, typing performance was modulated by a combination of psycholinguistic factors (e.g., letter frequency, age of acquisition) and

1 physical constraints (e.g., distance between keys on the keyboard). The magnitude  
2 of these effects decreased with grade. A complementary analysis showed that the  
3 number of fingers used for typing, a correlate of typing expertise in adults (Pinet et  
4 al., 2022), modulated individual effects, both psycholinguistic (letter frequency) or  
5 motoric (distance between keys). Thus, the decrease in the magnitude of the  
6 observed effects was not simply a by-product of general performance improvement  
7 over grade; the correlation with number of fingers points to a specific contribution of  
8 expertise.

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16 The decreasing influence of psycholinguistic and motoric factors with grade  
17 could be a correlate of the ongoing organization of the typing process into an outer  
18 and an inner loop, particularly in our oldest participants (Logan & Crump, 2011). As  
19 the word task requires processes pertaining to both loops, it can provide evidence for  
20 their acquisition (Figure 1). In this task, we observed strong effects of  
21 psycholinguistic factors on IKIs that interacted with grade, in contradiction with adults  
22 where psycholinguistic variables such as lexical frequency affected IKIs  
23 independently of their expertise level (Pinet et al., 2022). Moreover, adults displayed  
24 “anticipatory” effects of motor-related factors such as transition percentage and  
25 bigram frequency already on RT, i.e., before word typing started, interacting with  
26 their expertise level. Here, such effects were absent in children. Different effects in  
27 children could be the signature of incomplete organization of psycholinguistic and  
28 motor processes compared to adults.

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36 In handwriting, a comparable evolution during learning exists in how  
37 information flows between processing levels (Kandel & Perret, 2015). Also, at the  
38 early stages of handwriting acquisition, children tend to use different functional units  
39 than adults to organize their written productions (Kandel et al., 2011). Similarly, in  
40 typing, representations in the outer loop might evolve with the development of  
41 orthographic representations. Moreover, it has been shown that the automatization  
42 of motor aspects of handwriting frees up resources for more complex processes  
43 (Grabowski, 2010; Graham et al., 2000; McCutchen, 1996). The same could be  
44 happening in typing.

1 We believe that a strength of our study is that it provides chronometric  
2 evidence on the evolution of typing behavior in school-aged children through the  
3 analysis of interkeystroke intervals. The IKIs recorded in the alphabet typing task  
4 appeared sensitive to measures of letter frequency and distance, thereby confirming  
5 that this task is well suited to index the processes driving the production of single  
6 keystrokes through the decomposition into typing movements (intervals and  
7 keypress durations). In particular, our results were consistent at the keystroke and  
8 word levels and could be compared directly with previous studies in adults (Pinet et  
9 al., 2022). Other keylogging studies resorted to mixture model analysis in order to  
10 separate the *mixture* of cognitive processes that underlie typing behavior. This  
11 approach allows separating cognitive processes according to their specific cognitive  
12 demands, and hence speed, by identifying fluent vs. non-fluent intervals during text  
13 production or copying (Roeser et al., 2024; Van Waes et al., 2021). As typing  
14 behavior relies on an intricate combination of complex cognitive processes, these  
15 chronometric approaches are extremely valuable to identify each process,  
16 characterize their acquisition, as well as their evolution with typing expertise.

### 31 **Text production on a keyboard**

32 Writing a text encompasses processes involved in keystroke and single word  
33 typing, but also includes formulation processes (Figure 1). Despite these additional  
34 processes, performance in text composition was strongly predicted by the speed of  
35 sentence copying. Pairwise correlations between the different tasks confirmed how  
36 intertwined typing performance is at the keystroke, word, and sentence levels (Figure  
37 4). Indeed, the speed of sentence copying was in turn associated with performance  
38 in single keystroke and word tasks, themselves correlated. Composition quality and  
39 fluency are thus largely determined by the automaticity of keystroke typing and  
40 spelling skills (Beers et al., 2017; Berninger et al., 2009; Graham, 2018; Jiménez &  
41 Hernández-Cabrera, 2019; Malpique et al., 2024). Accordingly, specific typing habits  
42 such as the number of fingers used for typing impacted the number of sentences  
43 generated in text production, pointing to its importance in the automatization of  
44 typing skills (Feit et al., 2016; Logan et al., 2016; Pinet et al., 2022). Still, the  
45 composition task revealed low remaining variance that was not captured by the  
46 sentence copying task. We should indeed acknowledge that we performed a

1 relatively coarse assessment of compositional quality compared to previous studies,  
2 as the focus of our study was elsewhere.  
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### 5 **Skill acquisition during development** 6

7 As previously stated, typing expertise shows complex interactions with  
8 linguistic and motoric factors in adults (Pinet et al., 2022). Overall, the magnitude of  
9 the experimental effects increases with expertise, such as effects of transition type  
10 (whether two letters of a bigram are typed with one or two hands) and keystroke  
11 position within a word. This pattern has been interpreted as reflective of the  
12 acquisition of typing expertise. Here, instead, the magnitude of the main effects  
13 decreased with grade, which could set aside skill acquisition in a developing  
14 compared to a fully developed spelling and motor system. This contrast further  
15 opens the question of whether and how development and training can be  
16 dissociated. Using an independent index of typing expertise previously identified  
17 (number of fingers used for typing) allowed us to show the contribution of the  
18 acquisition of expertise over and above a generic improvement of performance  
19 across grades. However, this index remains indirect and based on self-reports from  
20 children. Having complementary and quantitative measures representative of typing  
21 expertise, for instance assessed through video recordings, would provide a way to  
22 confirm, or challenge, this first result. Moreover, the present study focused on the  
23 special case of the development of typing skills without formal training. Following  
24 children's performance during a short training program allows assessing expertise  
25 acquisition quite independently of development (van den Bergh et al., 2015; Van  
26 Weerdenburg et al., 2019). In addition, assessing skill acquisition of children in a  
27 longitudinal fashion up until early adulthood would bridge the gap between studies in  
28 children and in adults, and might reveal a reversal of the pattern of interactions with  
29 increasing expertise. Van Waes et al. (2021) reported typing performance in a  
30 sample from 13 years old to adulthood and found the fastest typing speeds in  
31 individuals between 21 and 30 years old, although this result was not related to  
32 specific typing habits (e.g., years of experience, formal training).  
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56 Some specific analyses can give a more precise description of the trajectory  
57 of training and/or development. In particular, van den Bergh et al. (2015) fitted  
58 polynomial functions to a large dataset of typing training data and found that a third  
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order polynomial best fitted the data. They were further able to show that skill acquisition was not complete by the end of training as they could not identify inflection points that would reveal stabilized performance. The theory of automaticity, well suited to explain typing behavior (Logan, 2018), specifically predicts similar decay rates for means and standard deviations over the course of training (Logan, 1988). Approaches that quantitatively assess the non-linear decrease of typing latencies have yet to be applied to developmental instead of training typing data (in handwriting, see Gosse et al., 2021). The evolution of performance in typing skill acquisition in children would be expected to follow predictions of developmental rate, already demonstrated in other contexts (Kail, 1991; Śmigajewicz et al., 2021).

### **Limitations**

The rapid technological development and country-specific educational policies are likely to impact typing skills. Here, we described a strong improvement between Grades 5 and 6, which corresponds to the change between primary and secondary schools in the French school system. Comparison with countries where the transition from primary to secondary school happens at a different grade (more typically between Grades 6 and 7) would clarify whether this effect truly stems from chronological age and constitutes a developmental effect or if it is rather associated with the changes brought about by the secondary school environment.

In contrast with previous results in adults, some typing habits such as daily typing time or years of practice did not correlate with typing speed or grade, despite what could have been expected (Pinet et al., 2022). It must be noted that these predictors displayed rather low variance in our sample, which might have lessened the chance of finding significant correlations. A larger scale study would most likely alleviate these constraints and also allow for more elaborate analyses, such as fitting distributional curves.

In conclusion, this study constitutes one of the first reports of the acquisition of typing skills in school-aged children without formal training. We reported how typing habits and performance evolved over Grades 4 to 9, and characterized the progressive, although presumably incomplete, automatization of typing skills. Our results reveal the intricate combination of cognitive processes underlying typing

1 behavior in children and pave the way to future studies aimed at disentangling  
2 developmental effects and skill acquisition.  
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