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Abstract: The shift of writing habits in the general population calls for a better understanding of the possible consequences of typing practice on language processing. To address this issue, we have built a set of words and pseudowords differing by their ratio of bimanual transitions between letters, an index of typing difficulty. An effect of typing difficulty was observed in expert participants who were actually typing the items, and not in non-expert typists. We then tested whether word recognition performance, measured with the task of lexical decision, was impacted by typing expertise and the typing difficulty of words. Lexical decision latencies varied as a function of typing motor difficulty. The effect was mostly driven by lexical decision times for pseudowords. This constitutes a first suggestion that motor representations built during the acquisition and practice of the typing skill have a collateral effect on visual recognition processes leading to lexical decision.

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Motor expertise for typing impacts lexical decision performance

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Abstract

The massive shift of writing habits in the general population calls for a better understanding of the possible consequences of typing practice on language processing, including reading. To address this issue, we have built a set of words and pseudowords differing by their ratio of bimanual transitions between letters, an index of typing difficulty. The items with few bimanual transitions are difficult to type, whereas those with many transitions are easy. An effect of typing difficulty was observed in expert participants who were actually typing the items, and not in non-expert typists. We then tested whether word recognition performance, measured with the task of lexical decision, was impacted by typing expertise and the typing difficulty of words. Lexical decision latencies varied as a function of typing motor difficulty. The effect was mostly driven by lexical decision times for pseudowords. This constitutes a first suggestion that motor representations built during the acquisition and practice of the typing skill have a collateral effect on visual recognition processes leading to lexical decision. Changing writing habits could therefore impact reading processes.

Keywords: Typing, lexical decision, expertise, interkeystroke intervals

Introduction

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2
3 Handwriting is still widely taught in elementary schools throughout the world. It is a long and, for
4
5 some children, painful learning experience which has always been mandatory at school since it has
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7 always been the most used form of written communication. Nowadays, typing is clearly becoming
8
9 the dominant writing modality in adulthood and perhaps even earlier. This massive shift of practice
10
11 in the adult population brings into question the legitimacy of handwriting teaching at school.
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13 Indeed, to many people's minds, handwriting is nothing more than a tool at the service of written
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15 communication and, when a tool becomes obsolete, it should be replaced by a more modern one.
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17 According to this point of view, handwriting should be replaced by typewriting at school. Is
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19 handwriting no more than a tool however, and what cognitive changes might occur if typing should
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21 takes its place at school? What, if any, would be the possible consequences of typing practice on
22
23 language processing in general, and on reading in particular?
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31 Although reading and writing have typically been studied separately, as if they were
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33 encapsulated systems, some researchers have hypothesized the existence of specific directional
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35 influences of the motor aspects of writing on reading, the rationale being that reading acquisition
36
37 and practice is supported by contemporaneous performance of writing gestures [1-3].
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42 Empirical evidence has been reported showing that knowledge of handwriting movements favors
43
44 the visual recognition of letters and the associated neural substrates [4-6; for a review see 7]. Letter
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46 recognition being one of the earliest steps in word reading, motor knowledge is likely to affect
47
48 skilled reading [8-9]. Beyond single letter identification, it is nonetheless still impossible to affirm
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50 that teaching typing instead of handwriting would have an effect on reading whole words (but see
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52 [10]).
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57 When compared to handwriting, typing practice has been revealed to be less efficient in single
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59 character recognition, presumably because the movement performed in striking a given key bears
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1 no relationship to the shape of the character to be recognized [4-5, 11-12]. Empirical studies
2 comparing the effects of typing and handwriting practice on letter recognition nonetheless suffer
3 from the same limitation: For ethical or practical reasons, training has been limited to short time
4 periods, usually a few weeks. This limitation has two main consequences, at the linguistic and
5 motor levels. As regards the linguistic level, the children or adult participants were not taught for
6 long enough to allow the assessment of their true lexical knowledge and reading capacity. As
7 concerns the motor level, the participants tested were hunt-and-peck typists who displayed poor
8 typing skills and variable associations between fingers and keys and thus any possible benefit of
9 typing on reading could not be tested.
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22 To overcome these limitations, another strategy consists of testing whether expert typists exhibit
23 reading capacities which are somehow influenced by their typing habits. Of course, expert typists
24 have been taught handwriting but usually they also learned typing early at school and, because of
25 their professional activity, they type much more often than they write by hand.
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33 Typing expertise is characterized by very strong and systematic associations which rely on
34 stable motor representations that bind systematically with visual representations of the characters
35 [13-14]. Rieger [13] showed for instance that in a task involving the visual display of single letters,
36 and although the task bore no direct relationship to typing, the finger responses that matched the
37 letters were facilitated in skilled typists, but not in hunt-and-peck typists, suggesting stable motor-
38 perceptual interactions in the former population. Furthermore, and crucial to our purposes, while the
39 shape of the characters is fundamental in handwriting, a critical dimension of typing is the sequence
40 of keystrokes corresponding to the sequence of letters composing the words. One of the major
41 differences between expert and hunt-and-peck typists is that the former use both hands, the right
42 hand to hit the keys on the right part of the keyboard and the left hand for the keys on the left part,
43 whereas the latter do not respect this systematic rule in typing and more often use their dominant
44 hand whatever the position of the key. It has been shown that choosing between two fingers of
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1 different hands is easier than choosing between two fingers of the same hand [15]. Furthermore,
2 alternating bimanual hits give rise to a higher and less variable typing rate than when using a single
3 hand [16]. These motor reasons might explain why, in experts, a remarkably stable motor feature of
4 typing movements is that cross-hand (bimanual) inter-keystroke intervals are shorter than within-
5 hand (unimanual) inter-keystroke intervals [14, 17-19]. This motor transition effect implies that, for
6 an expert, a word containing a majority of bimanual transitions is much easier to type than a word
7 containing mostly unimanual transitions [20]. This pattern is not present in novice typists [21].

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18 A few studies suggest that, in experts, this bimanual motor facilitation has a counterpart in the
19 perceptual processing of letter pairs. Van Den Bergh, Vrana and Eelen [22], and Beilock and Holt
20 [23] showed that skilled typists spontaneously prefer pairs of letters usually typed with two different
21 fingers relative to pairs usually typed with the same finger. Similar effects were also observed in a
22 memory task [24]. This suggests that typing expertise can lead to an activation of specific motor
23 patterns in perceptual tasks provided that the associated motor representations are stable, but the
24 evidence is scarce and its application to visual recognition is not straightforward.

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36 The aim of the present study was therefore to directly test whether word recognition, as indexed
37 by the paradigmatic task of lexical decision, was impacted by typing expertise. We designed a set of
38 French words in which we manipulated the number of cross- and within-hand transitions and
39 counterbalanced other relevant properties. For the expert typists, these words varied according to
40 their writing difficulty between ‘*easy*’ words, those with many bi-manual transitions, and ‘*difficult*’
41 words, those with few bi-manual transitions. We then tested whether lexical decision performance
42 for those words and for matched pseudowords showed a differential effect of motor difficulty in
43 expert and non-expert typists. Observing increased lexical decision times for items which were
44 difficult to type would be a strong suggestion that typing knowledge is activated in the course of
45 visual word recognition. Such an effect is expected for expert but not for non-expert typists.

Methods

Participants. The experiment was designed to include sixteen participants per group. This number was set to optimize the counter-balancing of the tasks and finger / response button matching. To reach this number, twenty expert typists (formally trained in touch-typing), French native speakers, had to be tested. Four of them produced errors rates exceeding 40% in the typing task of the trials and had to be replaced by another 4 typists. The control group was then composed of 16 participants without major experience of typing, selected to match the typists for age, gender, education and handedness. Non-experts usually typed with a maximum of three fingers per hand and lacked any formal training in a standard typing method. None of the participants in the control group had to be discarded but one turned out to be an expert (see below).

For all participants, we checked the declared degree of typing expertise with a questionnaire on their writing habits (Table 1) and a computerized typing pretest, programmed with Presentation® 16.3 (www.neurobs.com). The test yielded estimates of typing rate and accuracy based on two short texts that participants had to transcribe at their normal typing rate. Accuracy was defined on a per word basis. Typing rate was calculated as the rate of words (5 characters) typed per minute [25]. Finally, we recorded videos of the participants while they did the typing pretest to ensure that experts and non-experts used the number and position of fingers expected for each group.

One of the non-expert participants was finally re-assigned to the experts group, given her very good typing performance and her use of 10 fingers, despite her self-report of typing habits. Eventually, then, the expert group included 17 participants (1 male/16 female) and the control group included 15 participants (1 male/14 female; Table 1).

Insert Table 1 about here

Stimuli.

We determined what the rules are regarding the letters that should be hit by the right and the left hands in French expert typists. As can be seen in figure 1, 15 letters are hit using the left and 11 using the right hand on a French keyboard. We discarded the left-hand letters “w”, “x”, “c” and “v” because these have no right hand counterpart in the AZERTY keyboard.

Insert Fig 1 about here

We searched the ‘Lexique’ database [26] for words that were typed with variable proportions of bimanual typing transitions on the standard French AZERTY keyboard (see Table 2).

Insert Table 2 about here

The 120 selected words were all 6 to 8 letters long. The experimental words were divided into 15 transition ratio categories (from 14%, for example "**pompiste**" to 85%, for example "**habitu**el"; bold letters being typed with the right hand). Across these 15 categories, the items were matched for: the hand used to type the first letter, the average number of letters typed with the left and right hand, lexical frequency, number of syllables and phonemes, presence / number of homophones and homographs, frequency of bigrams, number of orthographic and phonological neighbors (Levenshtein distance), and lastly orthographic regularity. Table 3 summarizes these properties, and shows that only bigram frequency and orthographic Levenshtein distance (old20) were significantly different across transition ratio categories.

Insert Table 3 about here

1 For the lexical decision task, we also prepared a list of 120 pseudowords, created by changing
2 one letter from each of the experimental words. The substitute letter respected the bimanual
3 transition structure of the base-word and led to a minimal trigram frequency given its position, of
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5 10.

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9 To these strictly controlled lists of stimuli, we added 36 words and 36 pseudowords with
10 transition ratios of 0 and 100% (i.e. typed with a single hand or hand transitions at every letter).
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12 These served as fillers and were not further analyzed, as it was not possible to identify in the
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14 ‘LEXIQUE’ database (or toolbox) sets of words with 0 and 100% transitions that respected the
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16 matching criteria for the experimental items as described above.
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24 **Procedure.** This report is part of a larger study of written language processing in expert and
25 non-expert typists, where each participant was involved successively in 4 different tasks that used
26 the same set of words: a typing to dictation task, a handwriting to dictation task, a lexical decision
27 task and a spelling task. Task order was counter-balanced across participants in a pseudo-random
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29 manner (Latin square). Here we report the specific methods and results of the tasks that permitted
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31 the testing of our hypothesis: the typing to dictation task and the lexical decision task. We checked
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33 that task order had no significant effect on performance in the two tasks of interest, and that it did
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35 not interact with the main factors.
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43 Using a high quality sound card, words and pseudowords were dictated to the participant who
44 was wearing headphones. The audio stimuli were recorded from a native female French speaker in
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46 an anechoic room and segmented with Audacity 2.0.3. For the typing task, a high quality video card
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48 and a CRT screen with a 70 Hz refresh rate were used to display the words typed by the participant.
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50 In both tasks, a QWERTY DirectIN Millisecond Accurate Keyboard (<http://www.empirisoft.com/>),
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52 adapted as an AZERTY keyboard with stickers on the keys, was used for collecting responses.
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54 Stimulus presentation and response recordings were controlled by the software Presentation® 16.3
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56 (<http://www.neurobs.com/>).
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2 **Tasks.**
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4 *Auditory Typing task.* In this task, participants had to type the dictated words. Only words were
5 presented, because of the impossibility of writing dictated pseudowords without spelling errors. The
6 words were dictated one per trial in a random order. Each trial started with a fixation cross in the
7 center of the screen, along with the auditory word presentation. Participants were instructed to start
8 typing as soon as they had identified the word. Typed letters were displayed on-line on the center of
9 the screen, replacing the fixation cross. The duration of each trial (stimulus plus input) was set to
10 4000 ms for experts and 5000 ms for non-experts. The task was split into two blocks of 60 words
11 separated by a brief pause.
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24 A response was considered incorrect if it included the backspace or a wrong key. The remaining
25 correct responses were used to calculate the response times (RTs: time between the beginning of the
26 trial and the first keystroke) and the average interkeystroke interval (IKI) per trial.
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34 *Visual Lexical decision task.* Participants were presented with the item (a word or a
35 pseudoword) and they had to decide as quickly and accurately as possible whether the visually
36 presented letter string formed a word they knew. Stimuli were presented in Times New Roman in
37 the center of the screen. The size of the words covered 3 to 4 degrees of the visual field. At the
38 beginning of each trial a fixation cross appeared at the center of the screen for 500 ms; then a word
39 or a pseudo-word was presented until the response was given. After the response, a blank screen
40 was displayed for 1000 ms. The order of presentation of words and pseudowords was randomized
41 and differed across participants. Responses were given by means of the two F1 and F2 keys of the
42 same Millisecond Accurate Keyboard, covered with a plastic board so that only the 2 response keys
43 (F1 and F2) were visible. Participants used their right index (F1) and right middle fingers (F2), and
44 the association between finger and response (word vs pseudoword) was counterbalanced across
45 participants. Both response times and error rates were collected.
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2 **Data processing and statistical analysis.**
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7 In the **Typing task**, we excluded the errors (18.7% for the expert group; 13.8 % for the non-
8 experts group). Outliers were considered after error detection. For each participant, response times
9 above and below 2.5 standard deviations from their mean were considered outliers and discarded
10 from the data-set (0.03% replacements for the experts, and 0.03% for the non-experts). The same
11 was done with IKIs (18.2% replacements for the expert group, and 16.8% for the non-experts group
12 – tot 17.5%).
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21 In the **Lexical decision** task, errors in discriminating words and pseudowords were discarded
22 from the dataset (4.5% for the expert group; 4.2 % for the control group – tot 4.4%).
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26 Outliers were identified on the sets of correct responses, for each participant as reaction time
27 (RT) above and below 2.5 standard deviations from the mean (2.7% for the expert group; 2.5% for
28 the control group – tot 2.6% for lexical decision) and the corresponding RTs were also discarded
29 from the dataset.
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36 The resulting RTs and IKIs were log-transformed [28] and examined with linear mixed
37 regression models ([28-29], software R, package lmerTest for models processing and p-values and
38 package LMERConvenienceFunctions for graphical representations). We constructed models for
39 each task separately. In all models, subjects and items were considered as random-effects while
40 group (expert vs non-expert), bimanual transition ratio and the interaction between the two were
41 considered as fixed effects. Bimanual transition ratio values were modeled as a continuous
42 predictor. Furthermore we included in the models all the linguistic and task-dependent variables that
43 reached significance, discarding those that failed to reach significance.
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58 Error rates in both tasks were also analyzed using logistic regression models with the same
59 predictor structure as the models used for RTs. The results are reported only when significant.
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Results

Typing task.

Errors. The error analysis showed a significant effect of group ($\beta=-0.59$, $SE=0.28$, $z=-2.06$, $p<0.05$), the experts making more errors than the non-experts.

Response times. In the final model we included the number of phonemes in the word, frequency, the bigrams frequency, the orthographic Levenshtein distance (old20) and the hand used to type the first letter. The only effect that reached significance was the difference between the groups (fig. 2): As expected, the experts exhibited a shorter time to type the first letter of the words than the non-experts ($\beta =0.2$, $SE=0.04$, $t=5.5$, $p<0.001$). However, no effect of difficulty (bimanual transition ratio) was observed, and the group by difficulty interaction did not reach significance.

IKIs. In the final model we included the number of letters in the word, frequency, bigrams frequency, the orthographic Levenshtein (old20) distance and the hand used to type the first letter. All the variables of interest reached significance. Although the analysis was actually done taking into account the 15 categories of bimanual transitions, for the sake of clarity the data from the 15 categories have been combined into 3 categories of difficulty: difficult words (with a low ratio of bimanual transition, 14 to 33%), medium words (with a medium ratio of bimanual transition, 40 to 60%), and easy words (66 to 85% of bimanual transitions). As can be seen in figure 2, the IKIs were shorter in expert than in non-expert typists ($\beta =0.2$, $SE=0.06$, $t=3.3$, $p<0.01$). Furthermore, IKIs were modulated by the typing difficulty ($\beta =-0.002$, $SE=0.0003$, $t=-6.7$, $p<0.001$), although in an opposite manner between experts and non-experts: The interaction between group and difficulty was highly significant: $\beta =0.003$, $SE=0.0002$, $t=16.6$, $p<0.001$.

Insert fig. 2 about here

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2 Splitting the two groups into two separate databases allowed us to test whether the effect of
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4 difficulty was significant within each group. The effect of difficulty was highly significant for both
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6 groups, yet in opposite directions: In experts, IKIs increased as the difficulty increased ($\beta = -0.002$,
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8 $SE=0.0003$, $t= -5.7$, $p<0.001$) whereas in non-experts IKIs decreased as difficulty increased (β
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10 $=0.001$, $SE=0.0003$, $t=5.1$, $p<0.001$). In other words, in the expert typists, the greater the number of
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12 bimanual transitions in the words, the lower the difficulty to type them, whereas the reverse pattern
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14 was obtained in the non-expert typists. The complete results of the models are reported in appendix
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16 (Table A1).
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24 **Lexical Decision**

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26 We included in the model: trial rank, frequency (of the word or of the base-word for
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28 pseudowords [31]) and number of letters.
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31 Detailed effects on RTs are reported in appendix (Table A2). As expected, the standard
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33 lexicality effect was in evidence: pseudowords were associated with longer RTs than words (787 ms
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35 (sd = 219) & 694 ms (sd = 189) respectively, $\beta = -0.16$, $SE = 0.03$, $t=-5.9$, $p<0.001$). As a whole,
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37 expert and non-expert typists responded at the same speed in the lexical decision task (732 ms (sd =
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39 177) & 750 ms (sd = 240), respectively, ns). Finally, no difficulty effect was observed.
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43 However, the interaction between group and difficulty was significant ($\beta = 0.0006$, $SE = 0.0003$,
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45 $t= 2.45$, $p<0.05$), meaning that the difficulty effect was different in experts and non-experts.
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48 Furthermore, the Lexicality by group by difficulty two-way interaction approached significance (β
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50 $= -0.0007$, $SE = 0.0004$, $t = -1.8$, $p=0.06$). In other words, the effect of difficulty was different in
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52 experts and non-experts and varied between words and pseudowords. In order to estimate more
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54 precisely the interaction between group and difficulty, we analyzed the word and pseudoword
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56 datasets separately.
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Words. The model included the trial rank, frequency, and the orthographic Levenshtein distance (old20). The analysis revealed neither a significant group effect, nor a difficulty effect, nor a significant group by difficulty interaction.

Pseudowords. The model included the trial rank and the number of letters in the word. The analysis revealed neither a significant group effect, nor a difficulty effect. However, the group by difficulty interaction reached significance ($\beta = 0.0006$, $SE = 0.0002$, $t = 2.6$, $p < 0.01$). As can be seen in figure 3, in the lexical decision for pseudowords, the same trend as in the words typing task can be observed: In experts, the detection of pseudowords tended to slow down as the typing difficulty increased, while in non-experts the trend was opposite.

Insert Fig. 3 about here

Discussion

The results of this experiment can be summarized as follows:

1- in the typing task, as expected, the experts were faster than the non-experts to hit the first letter of the words (response time) and to type the following letters (IKIs),

2- in the typing task, the experts displayed the ‘difficulty’ effect: They were faster to type the ‘easy’ words, those involving many bimanual transitions, and slower to type the ‘difficult’ words. The non-experts showed the opposite pattern.

3- in the lexical decision task, both groups had the same overall mean RT but the ‘typing difficulty’ had a different impact on RTs for pseudowords in experts and non-experts. In experts, it took longer to identify the difficult pseudowords than the easy ones. In non-experts, the opposite trend was observed.

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2 The first two results confirm that the two groups who participated to this experiment actually
3
4 had a different level of expertise as regards typewriting. The experts typed the words more quickly
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6 and they, in particular, showed the expected difficulty effect: they typed the ‘easy’ words, those
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8 composed of a sequence of letters involving both hands alternately, more quickly than the ‘difficult’
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10 words, i.e. those involving few alternations between hands. It is worth noting that this difficulty
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12 effect only affected motor execution and had no influence on motor preparation since it was not
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14 present in the response times. It thus resulted from a motor effect linked to the advantage of using
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16 both hands instead of one [15-16], and not from some central cognitive / linguistic processes related
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18 to the spelling / meaning of the word. Therefore, we may guess that if pseudowords had been typed
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20 in the present experiment, the same difficulty effect would have been observed.
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29 Surprisingly, and at variance with the hypothesis of unreliable strategies in non-experts [21], the
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31 typing difficulty systematically affected the IKIs of this group, yet in the opposite direction. The
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33 video recordings we made during typing revealed that non experts use their right hand to type the
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35 great majority of the letters with the occasional recruitment/ involvement of the left hand,
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37 presumably when the coordination of right hand fingers was too demanding. In this way, most of
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39 the transitions between letters become unimanual for non-experts. When only the right hand is used,
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41 the IKIs depend mostly on the distance between successive keys: the longer the distance, the greater
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43 the IKI. The distance separating the keys of the left and right side of the keyboard, which are hit by
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45 different hands in experts (bimanual transition), are obviously longer than those separating keys
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47 usually hit by the same hand (unimanual transition). This could explain why IKIs were larger in
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49 non-experts for the easy words, in contrast to experts.
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58 This differential effect on motor execution in typing provides the groundwork for the main
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60 result of the study (result 3), namely that the motoric difficulty during typing had a significant
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1 perceptual effect on the visual lexical decision task. In other words, accessing the mental lexicon to
2 decide whether a letter string constitutes a word somehow depends on the motor representations
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4 associated with the usual production of that same word on the keyboard. Writing habits thus
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6 influence linguistic processes. Although the present experiment was designed to evidence an effect
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8 of motor knowledge on lexical decision rather than to identify the locus of this effect in the lexical
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10 decision processes, two hypotheses can be drawn to account for our results: First, the influence of
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12 typing knowledge could stem from an early stage of orthographic processing, where letter strings
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14 are visually processed. Given previous evidence of motor-perceptual interactions for written visual
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16 stimuli at the level of single letters or letter pairs [7, 22-24], it is possible that in experts, visual
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18 perception of letter strings triggers the parallel activation of associated patterns of hand and finger
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20 typing movements, which could in turn exert an influence on the recognition processes. The
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22 stability of the motor patterns for typing would accordingly modulate the RTs.
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30 The second and not mutually exclusive possibility is that over-training of the typing motor skills
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32 impacts written language processing at a higher level, through linguistic components that are
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34 common to both reading and spelling. This interpretation would imply two assumptions. First, the
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36 execution of the motor response in written production is not an isolated process, but is in fact
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38 carried out in strong interaction with the upstream (orthographic) spelling processes [32-34]. The
39
40 repetitive performance of peripheral writing execution could shape and influence spelling
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42 procedures. Secondly, there must be some components common to the cognitive architectures of
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44 reading and spelling [35-37]. Despite a tradition of separate investigations of reading and writing,
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46 some authors assume shared cognitive components such as the orthographic and phonological
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48 lexicons [37-38] or the graphemic buffer [39-41]. In the specific case of typing, Purcell, Napoliello
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50 and Eden [42] have recently shown that brain regions known to process orthography and phonology
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52 of single words are commonly activated by reading and typed spelling.
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Although the effect of typing difficulty was significant overall, it was driven mostly by pseudo-word RTs. This selective effect on pseudowords is puzzling: It could be a consequence of the standard lexicality effect, with greater RTs to pseudowords than to words. It is thus possible that a longer cognitive (linguistic) processing in the case of pseudowords affords motor representations more time to be strongly activated and to be functionally relevant. This account is in keeping with the finding of a rather late timing of the activation of motor representations in cases of embodied visual perception [43-44].

Another important aspect is that pseudoword processing generates grapheme to phoneme conversion procedures which rely more on the activation of sub-lexical pathways involving single letters or letter pairs, than of a lexical pathway [41,45]. Motor-perceptual interactions occurring at the level of single letters or letter pairs are more likely to occur in the case of pseudowords. The same conclusion was reached in a recent study in which transcranial magnetic stimulation (TMS) over the premotor dorsal cortex, a main region of the writing network, during a lexical decision task increased RTs to pseudowords without affecting word recognition [46]. The authors interpreted this specific effect by the assumption that pseudowords are processed serially, at a sublexical level, while words are processed globally at a lexical level.

To conclude, in terms of letter identification, it has been previously shown that handwriting was better than typing (see [7] for a review). It was then suggested that reading might be affected in persons able to type but not to handwrite. However, these studies did not really address reading processes, at least at the word level (except to some extent [10]). In the present study, we took the opposite view: We decided to check whether word recognition would be modified by typing habits and we compared expert and non-expert typists in a word identification task. The results suggest that motor representations built during training and practice of the typing skill have a perceptual / cognitive effect when words are processed. The impact was limited to pseudowords however, and this point needs further investigation. In addition, we have compared adults who are either expert in

1 typing or not, but all were taught how to handwrite, therefore the group differences in term of
2 cognitive processes involved was probably not as significant as compared to persons who are only
3 able to type. Nevertheless, besides the theoretical implications for current models of reading, this
4 finding raises practical questions about introducing typing instead of handwriting at school [3,47].
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10 11 12 13 14 15 16 **Acknowledgements**

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Figures and tables captions

Table 1. Mean characteristics, writing performance and writing habits in the two samples of participants.

Table 2: Stimuli classification. Summary of the words used in the whole experiment with the number of letters and the ratio of bimanual transitions (expressed as a % of the total number of transitions within a given word ; for example the word “humour” has one transition from the right to the left hand between “u” and “r” out of 5 so its ratio is 20%).

Table 3: Controlled variables in the categories of transition ratio. The Levenshtein distance is a string metric for measuring the difference between two sequences of letters; OLD indexes the mean orthographic similarity between the word and the other words of the lexicon [27], and PLD indexes the phonological similarity between the word and the other words of the lexicon. First letter indexes the rank of the first letter typed with the right hand. We reported means and p values per category

Table A1: complete results of the mixed models used in the typing task

Table A2: complete results of the mixed models used in the lexical decision task

Fig. 1 Schematic representation of a French AZERTY keyboard. The keys hit by the left and the right hand of an expert typist are colored in red and blue, respectively. For sake of symmetry, the four letters “w”, “x”, “c” and “v” were not used to compose the words and pseudowords of the study.

Figure 2. Typing task. Response time values (ms) and IKI values (ms) in expert (black) and non-expert (grey) participants according to the level of difficulty (Rate of bimanual transitions) of the words. Data from 15 have been combined into 3 categories of difficulty (see text). The error bars represent the within-subject confidence intervals [30].

Figure 3. Lexical decision task. RT values (ms) in Expert (black) and Non-Expert (grey) participants according to the level of difficulty (rate of bimanual transitions) of the pseudowords. For clarity, the data have been pooled from 15 into 3 categories of difficulty (see text). The error bars represent the within-subject confidence intervals.

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Dear Editors,

We submit here the original article “Motor expertise for typing impacts lexical decision performance” for consideration in the special issue “Handwriting in a digital age” in Trends in Neuroscience and Education. This research presents data that suggest that the way usually write (or type) might impact linguistic processes as those of recognizing words and pseudowords. We assessed the word recognition abilities by the way of a lexical decision task in two groups of adults differing by their level of expertise in typing. The results show that expert and non-expert typists did not discriminate pseudowords in the same manner. We conclude that replacing handwriting by typing at school could therefore impact reading processes. We look forward to hearing the feedback on this research.

Sincerely,

Marieke Longcamp,

	Experts (N=17)	Non-experts (N=15)
Mean age	41.7	43.6
Daily handwriting time (minutes)	60.7	97.1
Daily typing time (minutes)	265	137.5
Typing experience (years)	24	16.6
Right handed (%)	70	90
Typing accuracy (%)	90	90
Typing rate (wpm)	40.6	28.5

Table 1

	32 six letters words	40 seven letters words	48 eight letters words
Percentage of bimanual transitions	20% - 8 words (i.e. humour)	16% - 8 words (i.e. plumier)	14% - 8 words (i.e. pompiste)
	40% - 8 words (i.e. rayure)	33% - 8 words (i.e. mouflon)	28% - 8 words (i.e. pingouin)
	60% - 8 words (i.e. madame)	50% - 8 words (i.e. gourdin)	42% - 8 words (i.e. peuplier)
	80% - 8 words (i.e. rumeur)	66% - 8 words (i.e. typique)	57% - 8 words (i.e. infusion)
		83% - 8 words (i.e. plaisir)	71% - 8 words (i.e. jalousie)
			85% - 8 words (i.e. habituel)

Table 2

transitions ratio	Consistency	Frequency	First letter	Nb syllables	Freq Bigrams	Nb phonemes	Old20	Pld20	Nb right letters	Nb left letters
	Means									
14	83.59	12.53	7	2.50	1332.96	6.50	2.63	2.31	4.38	3.63
16	80.04	26.98	5	1.88	1038.78	5.25	2.16	1.91	3.38	3.63
20	82.72	23.28	6	1.88	1212.65	4.38	1.93	1.71	3.00	3.00
28	80.63	11.20	3	2.75	1255.06	6.50	2.74	2.49	3.63	4.38
33	68.06	18.12	3	2.00	1418.41	5.00	2.15	1.81	3.50	3.50
40	86.69	45.49	6	1.88	1098.68	4.88	1.87	1.56	3.00	3.00
42	81.63	17.86	7	2.38	1422.50	6.63	2.45	2.26	4.00	4.00
50	82.24	48.88	6	2.25	1099.11	5.75	2.34	2.13	3.50	3.50
57	78.65	25.47	3	2.50	1609.06	6.13	2.53	2.04	3.88	4.13
60	82.53	55.87	6	2.13	1327.98	5.13	2.15	1.99	3.00	3.00
66	82.16	45.46	3	2.38	1327.14	5.88	2.20	2.05	3.50	3.50
71	80.02	20.24	7	2.63	1617.81	6.13	2.39	1.78	4.00	4.00
80	79.15	36.42	4	2.00	1178.20	4.38	1.91	1.72	3.00	3.00
83	85.00	40.58	8	2.25	1455.46	5.88	2.04	2.01	3.50	3.50
85	82.89	15.16	1	2.50	1912.56	5.88	2.05	1.68	3.88	4.13
F value	0.25	0.96	0.84	1.8	6.8	0.004	4.0	3.0	0.03	0.01
p value	ns	ns	ns	ns	p<0.05	ns	p<0.05	ns	ns	ns

Table 3

Appendix: Table A1

Typing task – IKIs mean				
	β	SE	t value	p value
Nb. letters	-0.016	0.008	-1.9	= 0.05
Frequency	-0.0004	0.0001	-4.4	< 0.001
Bigrams Frequency	-0.00006	0.00001	-5.4	< 0.001
Old20	0.06	0.01	4.3	< 0.001
First letter	-0.03	0.01	2.8	< 0.01
Groups	0.2	0.06	3.3	< 0.01
Transitions	-0.002	0.0003	-6.7	< 0.001
Transitions X Group	0.003	0.0002	16.6	< 0.001
Typing task – Expert typists group				
	β	SE	t value	p value
Frequency	-0.0005,	0.0001	-4.1	< 0.001
Bigrams Frequency	-0.00008	0.00001	-6.2	< 0.001
Old20	0.07	0.01	4.7	< 0.001
First letter	0.04	0.01	2.9	< 0.01
Transitions	-0.002	0.0003	-5.7	< 0.001
Typing task – Non-expert typists group				
	β	SE	t value	p value
Frequency	-0.0003	0.0001	-2.9	< 0.01
Bigrams Frequency	-0.00007	0.00001	-5.5	< 0.001
Transitions	0.001	0.0003	5.1	< 0.001
Typing task – Reaction times				
	β	SE	t value	p value
Nb. phonemes	-0.02	0.009	-2.3	< 0.05
Frequency	-0.0004	0.0001	-3.2	< 0.01
Bigrams Frequency	-0.00005	0.00001	-3.0	< 0.01
Old20	0.05	0.02	2.6	< 0.01
First letter	-0.05	0.02	-3.3	< 0.01
Groups	0.2	0.04	5.5	< 0.001
Transitions	0.0005	0.0004	1.3	ns
Transitions X Groups	0.0001	0.0002	0.5	ns

Appendix: Table A2.

Lexical Decision				
	β	SE	t value	p value
Trial rank	-0.00007	0.000008	-9.9	< 0.001
Frequency	-0.004	0.00009	-4.5	< 0.001
Nb. letters	0.01	0.007	2.3	< 0.05
Lexicality	-0.16	0.03	-5.9	< 0.001
Groups	-0.02	0.05	-0.4	ns
Transitions	-0.0004	0.0003	-1.2	ns
Transitions X Groups	0.0006	0.0003	2.45	< 0.05
Lexicality X Transitions X Groups	-0.0007	0.0004	-1.8	= 0.06
Lexical Decision - Pseudowords				
	β	SE	t value	p value
Trial rank	-0.0001	0.00001	-9.05	< 0.001
Nb. letters	0.03	0.007	3.7	< 0.001
Groups	-0.02	0.06	-0.4	ns
Transitions	-0.0003	0.0003	-1.6	ns
Transitions X Groups	0.0006	0.0002	2.6	< 0.01
Lexical Decision - Words				
	β	SE	t value	p value
Trial rank	-0.00006	0.00001	-5.4	< 0.001
Frequency	-0.0007	0.0001	-4.8	< 0.001
Old20	0.07	0.02	3.5	< 0.001
Groups	0.03	0.05	0.5	ns
Transitions	0.0004	0.0004	1.2	ns
Transitions X Groups	0.00004	0.0002	0.2	ns



Figure 1

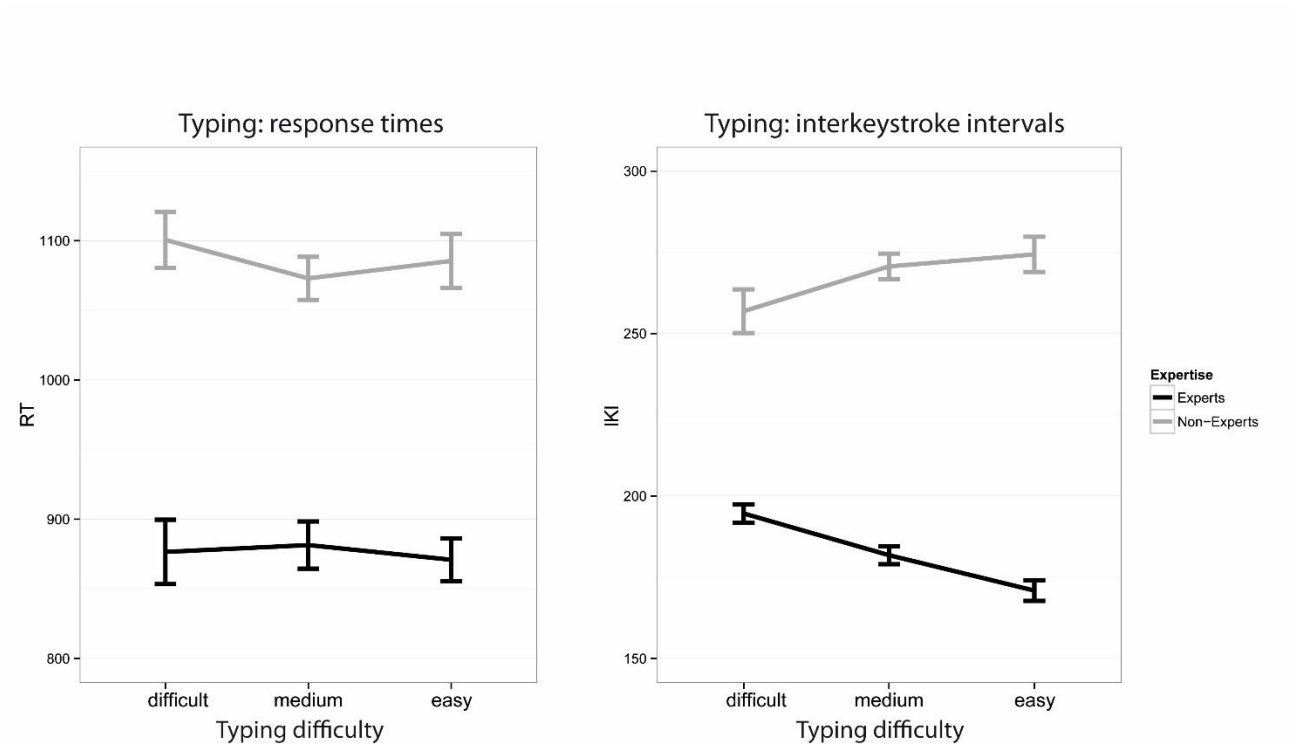


Figure 2

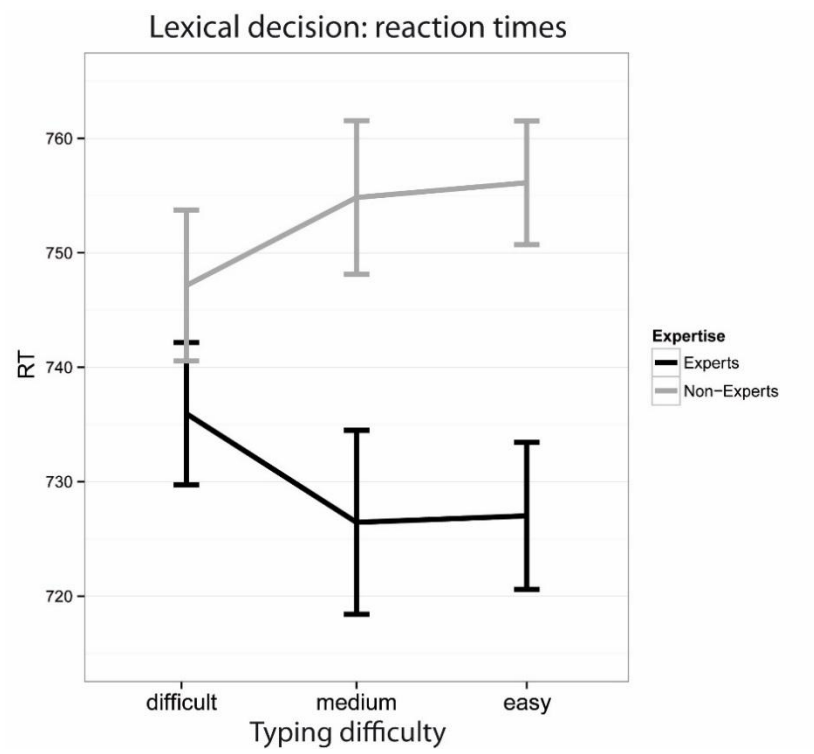


Figure 3